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NEW CONSTRUCTIONS IN GRAPHICAL STATICS.

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II.

THE ARCH RIB WITH FIXED ENDS.

LET us take, as the particular case to be treated, that of the St. Louis Bridge, which is a steel arch in the form of the arc of a circle; having a chord or span of 518 feet and a versed sine or rise of one-tenth the span, *i. e.* 51.8 feet. The arch rib is firmly inserted in the immense skew-backs which form part of the upper portion of the abutments. It will be assumed that the abutments do not yield to either the thrust or weight of the arch and its load, which was also assumed in the published computations upon which the arch was actually constructed. Further, we shall for the present assume the cross section of the rib to have the same moment of inertia, I, at all points, and shall here only consider the stresses induced by an assumed load. The stresses due to changes in the length of the arch itself, due to its being shortened by the loading, and to the variations of temperature, are readily treated by a method similar to the one which will be used in this article, and will be treated in a subsequent article.

Let $b_s\, a\, b_s'$ in Fig. 2, be the neutral axis of the arch of which the rise is one-tenth the span. Let $a\, x\, y\, z$ be the area representing the load on the left half of the arch, and $a\, x'\, y'\, z'$ that on the right, so that $yp = aP = xy$ on the left, and $yp = x'y'$ on the right.

Divide the span into sixteen equal parts bb_1, bb_1', etc, and consider that the load which is really uniformly distributed is applied to the arch at the points a, a_1, a_1', etc., in the verticals through b, b_1, b_1', etc.; so that the equal weights P are applied at each of the points on the left of a and the equal weights $\frac{1}{2}P$ at each point on the right of a, while $\frac{3}{4}P$ is applied at a.

Take b as the pole of a force polygon for these weights, and lay off the weights which are applied at the left of a on the vertical through b_s, viz., $b_s w_1 = \frac{1}{2}P$ = the weight coming to a from the left; $w_1 w_2 = P$ = the weight applied at a_1; $w_2 w_3 = P$ = the weight applied at a_2, etc. Using b still as the pole, lay off $b_s' w_1' = \frac{1}{4}P$ = the weight coming to a from the right; $w_1' w_2' = \frac{1}{2}P$ = the weight applied at a_1', etc. This amounts to the same thing as if all the weights were laid off in the same vertical. Part are put at the left and part at the right for convenience of construction. Now draw bw_1 until it intersects the vertical 1 at c_1; then draw $c_1 c_2 \parallel bw_2$; and $c_2 c_3 \parallel bw_3$,

etc. In the same manner draw bw_1' to c_1'; then $c_1' c_2' \parallel bw_2'$, etc. Then the broken line $bc_1 \ldots c_6$ is the equilibrium polygon due to the weights on the left of a, and $bc_1' \ldots c_6'$ is that due to the weights on the right. Had the polygon been constructed for the uniformly distributed load (not considered as concentrated) on the left we should have a parabola passing through the points $bc_1 \ldots c_6$, and another parabola on the right through $bc_1' \ldots c_6'$. From the properties of this parabola it is easily seen that c_6 must bisect $w_4 w_6$, as c_6' must also bisect $w_4' w_6'$; which fact serves to test the accuracy of our construction. This test is not so simple in cases of more irregular loading.

The equilibrium polygon $c_6 b c_6'$ is that due to the applied weights, but if these weights act on a straight girder with fixed ends, this manner of support requires that the total bending be zero, when the sum is taken of the bending at the various points along the entire girder; for, the position of the ends does not change under the action of the weights, hence the positive must cancel the negative bending. To express this by our eqs.:

$$yb = e. \quad \Sigma(M) = 0 \quad \therefore \quad \Sigma(M) = 0.$$

This is one of two conditions which are to enable us to fix the position of the true closing line $h_6 h_6'$ in this case. The other condition results from the fact that the algebraic sum of all the deflections of this straight girder must be zero if the ends are fixed horizontally.

This is evident from the fact that when one end of a girder is built in, if a tangent be drawn to its neutral axis at that end, the tangent is unmoved whatever deflections may be given to the girder; and if the other end be also fixed, its position with reference to this tangent is likewise unchanged by any deflections which may be given to the girder. To express this by our eqs.:

$$yd = f. \quad \Sigma(Mx) = 0 \quad \therefore \quad \Sigma(Mx) = 0$$

The method of introducing these conditions is due to Mohr. Consider the area included between the straight line $c_6 c_6'$ and the polygon $c_6 b c_6'$ as some species of plus loading; we wish to find what minus loading will fulfill the above two conditions. Evidently the whole negative loading must be equal numerically to the whole positive loading, if we are to have $\Sigma(M) = 0$. Next, as the closing line is to be straight, the negative load $c_6 c_6' h_6 h_6'$ may be considered in two parts, viz., the two triangles, $c_6 c_6' h_6$ and $c_6' h_6 h_6'$. Let the whole span be trisected at t and t', then the total negative loading may be considered to be applied in the verticals through t and t', since the centers of gravity of the triangles fall in these verticals. Again, the positive loading we shall find it convenient to distribute in this manner: viz., the triangle $c_6 b c_6'$ applied in the vertical through b, the parabolic area $b c_1 \ldots c_6$ in the vertical 4 which contains its center of gravity, and the parabolic area $bc_1' \ldots c_6'$ in 4'.

Now these areas must be reduced to equivalent triangles or rectangles, with a common base, in order that we may compare the loads they represent. Let the common base be half the span: then $bb_0 = pp'$ is the positive load due to the triangle $c_6 b c_6'$; and $\frac{2}{3} c_4 c_6 = pp_1$ and $\frac{2}{3} c_1' c_6' = p'p_1'$ are the positive loads due to the parabolic areas.

Now assume any point q as a pole for the load line $p_1 p_1'$ and find the center of gravity of the positive loading by drawing the equilibrium polygon, whose sides are parallel to the lines of this force polygon: viz., use qp_1 and qp as the 1st and 2nd sides, and make $pq' \parallel qp'$, and $q'q_1 \parallel qp_1'$. The first and last sides intersect at q_1; therefore the center of gravity of the positive loads must lie in the vertical through q_1.

Now the negative loading must have its center of gravity in the same vertical, in order that the condition $\Sigma(Mx) = 0$ may be satisfied, for it is the numerator of the general expression for finding the center of gravity of the loading. The question then assumes this form: what negative loads must be applied in the verticals through t and t' that their sum may be $p_1 p_1'$, and that they may have their center of gravity in the vertical through q_1.

The shortest way to obtain these two segments of $p_1 p_1'$ is to join r and r' which are in the horizontals through p' and p_2', and draw an horizontal through q_0, which is the intersection of $r r'$ with the vertical through q_1; then $r r_1$ and $r' r_1'$ are the required segments

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of the negative load. For, let $r\,r_2 = p_1' p_1$ and take r' as the pole of the load $r\,r_2$; then, since $r_1 q_0 \parallel r_2 r'$ and $q_0 r' \parallel r\,r'$ we have the equilibrium polygon $r_1 q_0 r'$ fulfilling the required conditions.

Now these two negative loads $r_1 r_2 = r_1' r'$ and $r\,r_1$, are the required heights of the triangles $c_2 h_2 c_2'$ and $c_2 c_2' h_2'$; therefore lay off $c_2 h_2 = r' r_1'$ and $c_2' h_2' = r r_1$.

The closing line $h_2 h_2'$ can then be drawn, and the moments bending the straight girder will then be proportional to $h_1 c_1$, $h_2 c_2$, etc., the points of inflexion being where the closing line intersects the polygon. If the construction has been correctly made, the area above the closing line is equal to that below, a test easy to apply.

Let us now turn to the consideration of the curve of the arch itself, and treat it as an equilibrium polygon. Since the rise of the arch is such a small fraction of the span, the curve itself is rather flat for our purposes, and we shall therefore multiply its ordinates ab, $a_1 b_1$, etc., by any number convenient for our purpose: in this case, say, by 3. We thereby get a polygon $d_2 d\, d_2'$ such that $d\,b = 3\,ab$, $d_1 b_1 = 3\,d_1 b_1$, etc. If a curve be described through $d_2 \ldots d \ldots d_2'$ it will be the arc of an ellipse, of which d is the extremity of the major axis.

If we wish to find the closing line $k_2 k_2'$ of this curve, such that it shall make $\Sigma(Md) = 0$ and $\Sigma(Mdx) = 0$, the same process we have just used is here applicable; but since the curve is symmetrical, the object can be effected more easily. By reason of the symmetry about the vertical through b, the center of gravity of the positive area above the horizontal through b lies in the vertical through b. The center of gravity of the negative area lies there also; hence the negative area is symmetrical about the center vertical; the closing line must then be horizontal. It only remains then to find the height of a rectangle having the same area as the elliptical segment, and having the span for its base. This is done very approximately by taking (in this case where the span is divided into 16 equal segments) $\frac{1}{8}$ the sum of the ordinates $b_1 d_1$, etc.

We thus find the height bk and the horizontal through k is the required closing line.

Before effecting the comparison which we intend to make between the polygons c and d (as we may briefly designate the polygons $c_2\,b\,c_2'$ and $d_2\,d\,d_2'$), let us notice the significance of certain operations which are of use in the construction before us. One of these is the multiplication of the ordinates of the polygon or curve a to obtain those of d. If a was inverted, certain weights might be hung at the points a_1, a_2, etc., such that the curve would be in stable equilibrium, even though there are flexible joints at these points. Equilibrium would still exist in the present upright position under these same applied weights, though it would be unstable. If now, radiating from any point, we draw lines, one parallel to each of the sides aa_1, $a_1 a_2$, aa_1', etc., of the polygon, then any vertical line intersecting this pencil will be cut by it in segments, which represent the relative weights needed to make a their equilibrium polygon. By drawing the vertical line at a proper distance from the pole, its total length, *i. e.*, the total load on the arch can be made of any amount we please. The horizontal line from the pole to this vertical will be the actual horizontal thrust of the arch measured on the same scale as the load. If a like pencil of radiating lines be drawn parallel to the sides of the polygon d and the load be the same as that we had supposed upon the polygon a, it is at once seen that the pole distance for d is one-third of that for a; for, every line in d has three times the rise of the corresponding one in a, and hence with the same rise, only one-third the horizontal span. The increase of ordinates, then, means a decrease of pole distance in the same ratio, and vice versa. As is well known, the product of the pole distance by the ordinate of the equilibrium polygon is the bending moment. This product is not changed by changing the pole distance.

Again, suppose the vertical load-line of a force polygon to remain in a given position, and the pole to be moved vertically to a new position. No vertical or horizontal dimension of the force polygon is affected by this change, neither will any such dimension of the equilibrium polygon corresponding to the new position of the pole be different from that in the polygon corre-

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sponding to the first position of the pole; the direction of the closing line, however, is changed. Thus we see that the closing line of any equilibrium polygon can be made to coincide with any line not vertical, and that its ordinates will be unchanged by the operation. It is unnecessary to draw the force polygon to effect this change.

Now to make clear the relationship between the polygons c and d, let us suppose, for the instant, that the polygon e has been drawn by some means as yet unknown, so that its ordinates from d, viz., $e_1 d_1 = y_1$, $e_2 d_2 = y_2$, etc., are proportional to the actual moments Me which tend to bend the arch.

The conditions which then hold respecting these moments Me, are three:—

$$\Sigma(Me)=0,\ \Sigma(Mex)=0,\ \Sigma(Mey)=0.$$

The first condition exists because the total bending from end to end is zero when the ends are fixed. The second and third are true, because the total deflection is zero both vertically and horizontally, since the span is unvariable as well as the position of the tangents at the ends. These results are in accordance with Prop. V. Now by Prop. III these moments Me are the differences of the moments of a straight girder and of the arch itself; hence the polygon e is simply the polygon c in a new position and with a new pole distance. As moments are unchanged by such transformations, let us denote these moments by Mc. We have before seen that

$$\Sigma(Mc)=0, \text{ and } \Sigma(Mcx)=0$$

Subtract

$$\therefore \Sigma(Mc-Me)=0, \text{ and } \Sigma(Mc-Me)x=0$$
$$\therefore \Sigma(Md)=0 \text{ and } \Sigma(Mdx)=0$$

From this it is seen that the polygon d must have its closing line fulfill the same conditions as the polygon c. This is in accordance with Prop. IV.

$$\text{Again, } \Sigma(Mey)=\Sigma(Mc-Md)y=0$$
$$\therefore \Sigma(Mcy)=\Sigma(Mdy).$$

This last condition we shall use for determining the pole distance of the polygon e, which is one-third of the actual thrust of the arch measured on the scale of the weights w_1 w_2, etc. The physical significance of this condition may be stated according to Prop. V, thus: if the moments Md are applied to a uniform vertical girder bd at the points b, b_1'', b_2'', b_3'', etc., at the same height with d_1, d_2, etc., they will cause the same total deflection $xd=\Sigma(Mdy)$ as will the moments Mc when applied at the same points. Hence if Md are used as a species of loading, we can obtain the deflection by an equilibrium polygon. Suppose the load at d_1 is $d_1 k_1$, and that at d_2 is $d_2 k_2$, etc., then that at d_3 is $\frac{1}{2} b_3 k_3$. This approximation is sufficiently accurate for our purposes.

Now lay off on $l_3 l_3'$ as a load line $dm_3=\frac{1}{2} b_3 k_3$, $m_3 m_2=d_2 k_2$, $m_2 m_1=d_1 k_1$, etc. The direction of these loads must be changed when they fall on the other side of the line k; e.g., $m_3 m_4=k_4 d_4$. If this process be continued through the entire arch m_5' (not drawn) will fall as far to the right of d as m_3 does to the left, and the last load will just reach to d again. This is a test of the correctness with which the position of the line $k_3 k_3'$ has been found. Now using any point as b for a pole, draw bm_3 to f_2, then draw $f_2 f_3 \parallel bm_2$, $f_3 f_4 \parallel bm_3$, etc. The curve bf is then the exaggerated shape of a vertical girder bd, fixed at b, under the action of that part of moments Md which are in the left half of the arch. The moments Md on the right may act on another equal girder, having the same initial position bd, and it will then be equally deflected to the right of bd. This is not drawn.

Again, suppose these vertical girders fixed at b are bent instead by the moments Mc. We do not know just how much these moments are, though we do know that they are proportional to the ordinates of the polygon c. Therefore make $dn_3=\frac{1}{2} h_3 c_3$, $n_3 n_2=h_2 c_2$, $n_2 n_1=h_1 c_1$, etc. When all these loads are laid off, the last one $n_3' d=\frac{1}{2} h_3' c_3'$ must just return to d. This tests the accuracy of the work in determining the position of $h_3 h_3'$.

Now using b as a pole as before, construct the deflection curves bg and bg'. Since these two deflections, viz., $2\,df$ and gg' ought to be the same, this fact informs us that each of the ordinates $h_1 c_1$, $h_2 c_2$, must be increased in the ratio of $\frac{1}{2} gg'$ to df, in order that when they are considered as loads, they may produce a total deflection equal to $2\,df$. To effect this, lay off $bj=df$ and $bi=\frac{1}{2} gg'$, and draw the horizontals through

i and j. At any convenient distance draw the vertical $i_0 j_0$, and draw bi_0 and bj_0. These last two lines enable us to effect the required proportions for any ordinates on the left, and these or two lines of the same slope on the right to do the same thing on the right. *E. g.* lay off the ordinate $bi_0' = h_0' c_0'$, then the required new ordinate is bj_0'. Then lay off $k_0' e_0' = bj_0'$. In the same manner find $k e$ from $h b$, and $k_0 e_0$ from $h_0 c_0$. In the same manner can the other ordinates $k_1 e_1$, etc., be found; but this is not the best way to determine the rest of them, for we can now find the pole and pole distance of the polygon e.

As we have previously seen, the pole distance is decreased in the same ratio as the ordinates of the moment curve are increased, therefore prolong bi_0 to v_1, and draw a horizontal line through v_1 intersecting bj_0 at v_2 and the middle vertical at v_0; then is $v_2 v_0$ the pole distance decreased in the required ratio. Hence we move up the weight-line $w_1 w_0$ to the position $u_1 u_0$ vertically through v_2; and for convenience, lay off the weights $w_1' w_2'$ at $u_1' u_2'$, etc.

Furthermore, we know that the new closing-line is horizontal. To find the position of the pole o so that this shall occur, draw bv parallel to hh_0, and from v the horizontal vo. As is well known, v divides the total weight into the two segments, which are the vertical resistances of the abutments, and if the pole o is on the same horizontal with v, the closing line will be horizontal.

Now having determined the positions of the points e_0, e, e_0', starting from one of them, say e_0, draw $e_0 e_7 \parallel ou_0$, $e_7 e_6 \parallel ou_1$, etc.; then if the work be accurate, the polygon will pass through the other two points e and e_0'. The bending moments of the arch d or the arch a at a_1, a_2, etc., is the product of the pole distance $v_0 v_2 = v'o$ by the ordinates $d_1 e_1$, $d_2 e_2$, etc., respectively, and between these points a similar product gives the moment with sufficient accuracy. It would be useful for the sake of accuracy to multiply the ordinates of the arch by some number greater than 3.

As a final test of the accuracy of the work, let us see whether $\Sigma(My)$ is actually zero, as should be. At d_7, for example, $y = d_7 l_7$ and $M e$ is proportional to $d_7 e_7$. Then $\overline{d_7 s_7}^2$ is proportional to My at that point if $e_7 s_7$ is the arc of a circle, of which $e_7 l_7$ is the diameter. Similarly find $d_7' s_7'$, etc. When e_4 for example falls above d_4, the circle must be described on the sum of $l_4 d_4$ and $d_4 e_4$ as a diameter, and $\overline{d_4 s_4}^2$ is proportional to a moment of different sign from that at d_4. We have distinguished the sign of the moments at the different points along the arch, by putting different signs before the letter s. It would have been slightly more accurate to have used only one-half the ordinates $b_0 e_0$ and $b_0' e_0'$, but as they nearly equal in this case and of opposite sign, we have introduced no appreciable error.

Now at any point s lay off $ss_7 = d_7 s_7$, and at right angles to it $s_7 s_8 = b_0 s_0$, then at right angles to the hypothenuse ss_8 make $s_8 s_0' = d_0' s_0'$, etc. Then the sum of the positive squares is ss_1', and similarly the sum of the negative squares is ss_1. If these are equal, then $\Sigma(My)$ vanishes as it should, and the construction is correctly made.

It would have been equally correct to suppose the two vertical girders fixed at d, and bent by the moments acting. We could have determined the required ratio equally well from this construction. Further, in proving the correctness of the construction by taking the algebraic sum of the squares, we could have reckoned the ordinates, y, from any other horizontal line as well as from $l_0 l_0'$.

To find the resultant stress in the different portions of the arch, we must prolong $v'o$ to o', say, (not drawn) so that the pole distance $v'o' = 3\, v'o$; then if we join o' and u_0, $o'u_0$ will be the resultant stress in the segment $b_0 a_1$; $o'u_1$ will be the stress in $a_1 a_2$, etc., measured in the same scale as the weights $w_1 w_2$, etc.

The vertical shearing stress is constructed in the same manner as for a girder, by drawing one horizontal through w_8 between the verticals 7 and 8, another through w_7 between 7 and 6, etc. (not drawn). Then the shear will be the vertical distance between vo and these horizontals through w_8, w_7, etc. It is seen that the shear will change sign on the vertical through b_1 with our present loading.

The actual position of the vertical through the center of gravity of the load may be found by prolonging the

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first and last sides of the polygon *c*. A weight $= \frac{1}{2} P = w_s\, w_9$ ought, however, first to be applied at b_9, and another $= \frac{1}{4} P = w_s'\, w_9'$ at b_s'. The shearing stress under a distributed load will actually change sign on this vertical. It will not pass far however from b_1.

The vertical shearing stress and resultant stress can be compounded and then resolved into normal and tangental components, if we should desire to obtain the stress along the arch and the normal shear.

As to the position of the moving load which will produce the maximum bending moments, we may say that the position chosen, in which the moving load covers one-half the span, gives in general nearly this case. It is possible, however, to increase one or two of the moments slightly by covering a little more than half the span with the moving load.

The maximum resultant stress and maximum vertical shear occur in general when the moving load covers the whole span. The construction in this case is much simplified, as the polygon *c* is then the same on the right of *b* as it now is on the left, and the center of gravity of the area is in the center vertical; so that the closing line $h_s\, h_s'$ is horizontal, and can be drawn with the same ease as $k_s\, k_s'$ was drawn. We shall not, even in this case, be under the necessity of drawing the curves *bg* and *bg'*, which would be both alike; for, as may be readily seen, the sum of the positive moments *Mc* on the left must be very approximately equal to the positive moments *Md* on the left, and the same thing is true for the negative moments at the left. The same two equalities hold also on the right. From this we at once obtain the ratio by which the ordinates of the polygon *c* must be altered to obtain those of the polygon *e*.

This last approximation also shows us that for a total uniform load, the four points of inflection when the bending moment is zero, lie two above and two below the closing line. It is frequently a sufficiently close approximation in the case when the moving load covers only part of the span to derive the ratio needed by supposing that the sum of all the ordinates, both right and left, above the closing line in the polygon *c* must be increased, so that it shall equal the corresponding sum in the polygon *d*. If the sums taken below the closing lines give a slightly different result, take the mean value.

Thus the single construction we have given in Fig. 2, and one other much simpler than this, which can be obtained by adding a few lines to Fig. 2, give a pretty complete determination of the maximum stresses on the assumptions made at the commencement of the article.

One of these assumptions, viz., that of constant cross section (*i. e.* I=constant), deserves a single remark. In the St. Louis arch I was increased one-half at each end for a distance of one-twelfth of the span. This very considerable change in the value of I slightly reduced the maximum moments computed for a constant cross section. From other elaborate calculations, particularly those of Heppel,* on the Britannia Tubular Bridge, it appears that the variation in the moments caused by the changes in cross section, which will adapt the rib to the stresses it must sustain, are relatively small, and in ordinary cases are less than five per cent. of the total stress. The same considerations are not applicable near the free ends of a continuous girder, where I may theoretically vanish. In the case before us, where the principal part of the stress arises not from the bending moments, but from the compression along the arch, the effect of the variation of I is very inconsiderable indeed.

* *Philosophical Magazine*, Vol. 40, 1870.

MENESSIER'S OSCILLATING PUDDLING FURNACE.—In the *Bulletin du Comité des Forges de France*, No. 112, for April 20th, 1876, will be found a communication made by M. Menessier to the Société de l'Industrie Minerale de St. Etienne, in which he describes a mechanical puddling furnace of his invention, which has been in work during the last seven or eight months at the Forges d'Ouzion, near St. Chamond. Full details of the working of this furnace are given, but space does not permit of our more than referring to the paper itself for particulars.

ON A GENERAL METHOD OF PRODUCING EXACT RECTILINEAR MOTION BY LINKWORK.

By A. B. KEMPE, B. A.

Proceedings of the Royal Society.

Since the invention by James Watt, in 1784, of the three bar linkwork known as "Watt's Parallel Motion," which gives an approximate rectilinear motion, many attempts have been made to obtain a more perfect solution of the problem how to obtain accurate rectilinear motion by means of linkwork. Prof. Tchebicheff succeeded in obtaining a three bar linkwork giving a much closer approximation to a true result; but in his case, as in that of others, the solution is only approximate, and it may be, in fact, shown that with three bars an accurate result cannot be obtained. It was not until 1864 that the problem was solved; in that year M. Peaucellier made his memorable discovery of an accurate seven bar solution; and in 1874, when the subject was brought prominently forward in England by Prof. Sylvester, Mr. Hart, in a paper read before the British Association, gave a solution by means of five bars. Both these linkworks, as is now well known, depended upon the inversion of a circle with respect to a point on its circumference.

M. Peaucellier's apparatus is shown in Fig. 10. P O, O K, K D, D P and four equal bars jointed together at their extremities; P B, K B are two bars also equal, but unequal to the four others; they are jointed to the others at P and K and to a fixed pivot at B. It is then easily seen that, however this linkage* is deformed, B, O, D remain in a straight line, and the product B O, B D is constant. Thus if D be made, by means of the bar A D jointed to the fixed point A, whose distance from B equals A D, to describe a circle through B, the point O will describe the inverse of the circle—that is, the straight line O L perpendicular to B A.

Mr. Hart's apparatus is shown in Fig. 15. For the six bars B P, B K, O P, P D, D K, K O of M. Peaucellier in Fig. 10 he substitutes the four bars

$$B C = B' C', \quad C D = C' D',$$

and takes three points, P, O, V, on a line parallel to C C'; these points, however the linkage be deformed, lie in a straight line, and the product P V, P O is always constant.

Thus V being made, by the bar V U equal to P U and pivoted at U, to describe a cirle passing through the fixed point P, as in the case of M. Peaucellier's linkwork, O describes the straight line O L perpendicular to P U.

A passage in a lecture on M. Peaucellier's discovery delivered by Professor Sylvester at the Royal Institution, in which he pointed out that there might be other solutions, led me to investigate the subject further; and I succeeded in obtaining certain seven bar linkworks producing rectilinear motion, depending on two bars being made to make equal variable angles in opposite directions with a third bar. These results were described in a paper published in the *Messenger of Mathematics* of December, 1874; they are shown in Figs. 6, 12, 13, 14 of this paper, and will be further referred to.

Further investigation led me to the discovery that all these linkworks depended for their production of straight lines on an exceedingly simple and obvious property of any quadrilateral whose sides are of constant length. The observation of this property at once led to the discovery of a large number of new seven bar linkworks, of which M. Peaucellier's, Mr. Hart's, and those previously discovered by myself proved to be particular cases, the inversion property of the two former being, so to say, accidental.

It is the object of this paper to point out this property, and how it may be taken advantage of in the construction of a number of seven bar straight-line-producing linkworks.

The property alluded to is this:

The cosines of the opposite angles of any quadrilateral whose sides are of constant length, but whose angles are variable, bear a linear relation to each other.

§ 1. In Fig. 1, A B C D is any quad-

* Professor Sylvester has employed this term to mean a network composed of an even number of bars. When one bar is fixed, so that its joints become fixed pivots, the system is termed a linkwork.

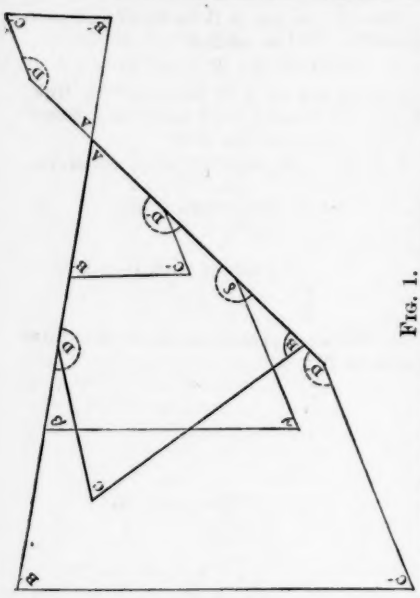


Fig. 1.

rilateral of which the sides A B, B C, C D, D A are of the lengths a, b, c, d respectively.

Then it is clear that

$$a^2+b^2-2ab\cos B=c^2+d^2-2cd\cos D \quad (1)$$

That is, there is a linear relation of the most general character between the cosines of the variable angles B and D.

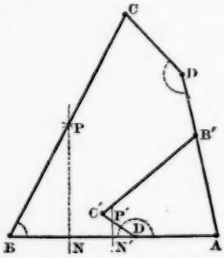
Before, however, this property can be taken advantage of something more is required; the angles whose cosines bear a linear relation to each other are the opposite angles of a closed quadrilateral; and for our purpose it is necessary that they should be the angles at the base of an open trilateral—*i e.*, to employ the language of linkwork, the angles made with a third bar by two bars which are jointed to it. To effect this transformation let the second quadrilateral $A\beta\gamma\delta$ be constructed equal in every respect to A B C D, and having its sides δ A, β A collinear with the sides B A, D A of A B C D, but placed in a reverse position so as to be the image of A B C D. This new quadrilateral may be termed the "conjugate image" of A B C D, the whole figure forming what may be termed a "self-conjugate sextilateral."

It is clear that the angle δ is equal to the angle D; thus we have the sides B C, $\delta\gamma$ of the open trilateral C B $\delta\gamma$ making angles with A B whose cosines bear a linear relation to each other however the figure be deformed.

Since, however, the relation is an angle relation, it is unnecessary that the conjugate image should be equal to the original quadrilateral; for if the Fig. A B′ C′ D′ be constructed similar to A $\beta\gamma\delta$ the angle D′ is clearly equal to the angle δ, and we have the sides C B, C′ D′ making angles with A B whose cosines bear a linear relation to each other. This makes our results more general; and we are moreover able to make the points D and B′, or the points D′ and B, coincide if necessary. This more general form of figure, consisting of two quadrilaterals, one of which is the enlarged or reduced positive or negative image of the other, may still be appropriately termed a "self-conjugate sextilateral," the quadrilaterals being still called the one the "self-conjugate image" of the other.

§ 2. Now let the linkage in Fig. 2 be constructed,

Fig. 2.



in which

A B$=a$,	A B′$=k\,a$,
B C$=b$,	B′ C′$=k\,b$,
C D$=c$,	C′ D′$=k\,c$,
D A$=d$,	D′ A$=k\,d$,

k being positive or negative, and greater, equal to, or less than unity, so that the linkage forms a self-conjugate sextilateral, the quadrilaterals A B C D, A B′ C′ D′ being self-conjugate images the one of the other.

Now take any point P on B C, and let B P $=\lambda$, and take a point P′ on D′ C′ such that $D'P'=\lambda\frac{cd}{ab}$. Draw P N and P′ N′ perpendicular to A B.

Then

$$BN=\lambda\cos B,$$

$$D'N' = \lambda \frac{cd}{ab} \cos D' = \lambda \frac{cd}{ab} \cos D,$$

and

$$B D' = a - kd.$$

Thus $N N' = B D' - B N + D' N'$*

$$= (a - kd) - \frac{\lambda}{2ab}[2\,ab \cos B - 2\,cd \cos D]$$

by (1)

$$= (a - kd) - \frac{\lambda}{2ab}[(a^2 + b^2) - (c^2 + d^2)] \quad . \quad (2)$$

a constant. On the other hand, $P N - P'N'$ is in general variable.

The linkage in Fig. 2, which will assume innumerable forms by giving different values to a, b, c, d, and k, is the fundamental linkage upon which the various linkworks here discussed depend. As the same lettering will be preserved throughout the diagrams, the fundamental linkage may be at once recognized in each figure showing its various adaptations.

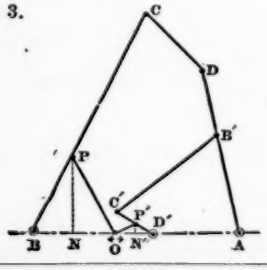
For clearness the bars are denoted by thick lines, the joints by round spots; when a bar becomes fixed so that its joints are fixed pivots, the bar is denoted by a broken line and the pivots by circles round the spots. When points in general separate are made coincident, the letters denoting all the coincident points are bracketed together. It is found convenient to collect the different linkworks into four groups, a separate section, numbered to correspond with the figure, being devoted to each separate linkwork described.

I. § 3. Take

$$\lambda = \frac{(a - kd)ab}{(a^2 + b^2) - (c^2 + d^2)}$$

so that $N N' = \frac{B D'}{2}$.

FIG. 3.



* In the figure $D' N'$ is negative.

Then if the bar A B be fixed and two bars P O, P′O be added

$$P O = P B, \quad P' O = P' D';$$

O clearly lies on A B, however the linkwork be deformed, and its locus is therefore the straight line A B.

§ 4. If in this last linkwork we make

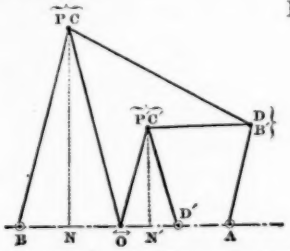
$$b = c, \; k = \frac{d}{a}, \text{ then } \lambda = b,$$

and

P coincides with C,
P′ " " C′,
B′ " " D.

The linkwork then assumes the form given in Fig. 4.

FIG. 4.



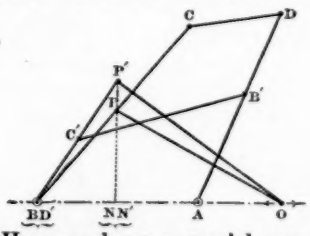
§ 5. Again, in the linkwork of § 3, if

$$k = \frac{a}{d} \text{ and } a^2 + b^2 = c^2 + d^2,$$

then $\lambda = \frac{0}{0}$ and is indeterminate. P may then be taken anywhere on B C; and since $N N' = 0$, P′ lies vertically above P. Also P O and P′ O may be taken of any lengths so long as

$$P' O^2 - P O^2 = P' B^2 - P B^2.$$

FIG. 5.



§ 6. Here we have a special case of the linkwork in the last section in which $a = -c$, $b = d$. In this case C B and C′D′ are equally inclined to B A in opposite directions; and the linkwork is one of those given by me in the *Messenger*.

§ 7. This case does not strictly come under the same head as those coming before, but is an exceptional one.

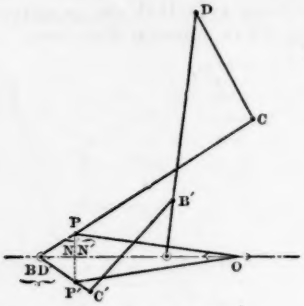


FIG. 6.

Since P and P′ in § 5 lie vertically the one over the other, it is clear that if the links P O=P′B, P′ O=P B be added, O lies on the straight line O B perpendicular to A B, and thus O B is the locus of O.

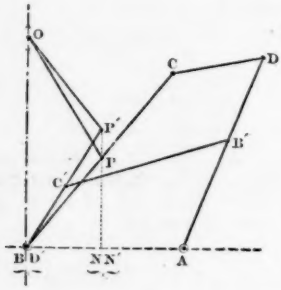


FIG. 7.

II. § 8. Make $k=\frac{a}{d}$ in the fundamental linkage, so that B and D′ coincide.

Fix A B, add the bars R P O, R P′ O′, making

R P = P O = P′D′,
R P′ = P′O′ = P B,

then R P O is parallel to P′D′,
R P′O′ " P B.

Thus, if O L, O′L′ be drawn perpendicular to A B,

N L = N′D′,
N′L′ = B N.

Therefore B L = B′L′ = N′N, a constant.

Thus the loci of O and O′ are two parallel straight lines perpendicular to A B.

The two added bars may clearly be replaced by the bars $\varrho C\omega$, $\varrho C'\omega'$ parallel to them; and the points ω, ω', where these bars cut the line O′ B O, will move in straight lines $\omega\lambda$, $\omega'\lambda$ perpendicular to A B.

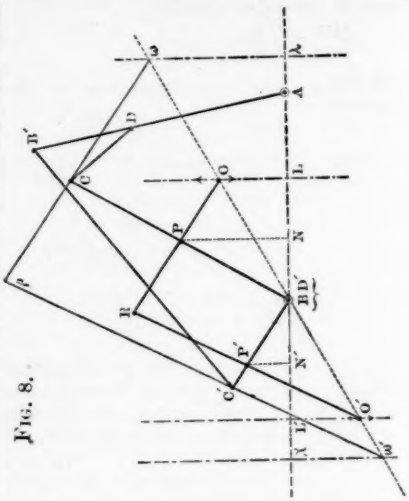


FIG. 8.

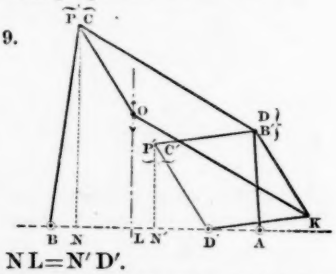
III. § 9. Fix A B.

Make $k=\frac{d}{a}$, $\lambda=b$.

Then P coincides with C,
P′ " " C′,
D " " B′,

Replace C′ D′, C′ B′ by the new bars
B′K = C′ D′, D′ K = C′ B′,
so that B′ K is parallel to C′ D.
Add the two bars
C O = B′K, K O = B′C,
so that P O is parallel and equal to D K, and therefore to C′ D′.
Draw O L perpendicular to A B.

FIG. 9.



Then N L = N′ D′.
Therefore B L = B N + N L = N N′, a constant.
Thus the locus of O is the straight line O L perpendicular to A B.

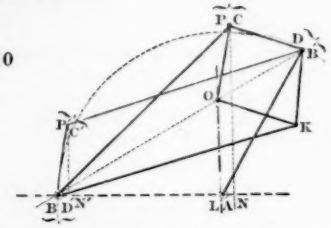
§ 10. Now in the last linkwork make
$a=d$.

Then B coincides with D′,

$$D'K=CB,$$
$$PO=OK=KD=DC,$$

and the linkwork becomes that of M. Peaucellier.

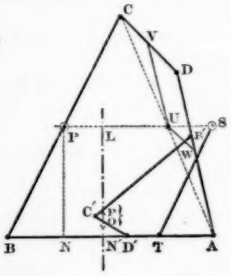
FIG. 10



IV. § 11. Taking the fundamental linkage in its most general form, fix the point P on a pivot. Now if the bar A B be made to remain always parallel to the fixed line P S, since N N′ is constant, P′ will move on the straight line P′ L perpendicular to P S.

The parallelism of A B is effected most obviously by adding the bar S T equal to P B, P S being equal to B T. Other methods may, however, be employed; for if C A be joined cutting P S in U, U is a fixed point; and if U V be drawn parallel to C D, U V is constant and V is a fixed point on C D. So if U W be drawn parallel to C D, U W is constant and W is a fixed point on A D. Thus the bar S T may be replaced by either of the bars U V or U W.

FIG. 11.



§ 12. In the case in which the bar S T is employed in the last section, make

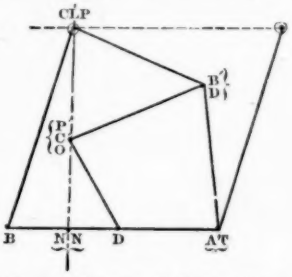
$$a=b,\ c=d,\ k=\frac{d}{a},\ \lambda=b,$$

and make T coincide with A. Then

C, L, P coincide,
P′, C′, O "
A, T "
B′, D "
N, N′ "

and the bars C D, D O are equally inclined to C S in opposite directions.

FIG. 12.



This linkwork is one of those given by me in the *Messenger*.

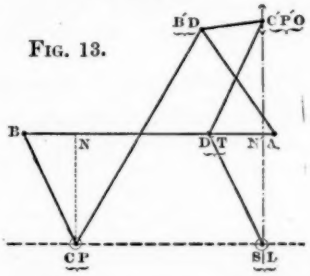
§ 13. In the linkwork of § 11 make

$a=c,\ b=-d,\ \lambda=b,\ =k\frac{d}{a}$, and make D′ and T coincide. Then

S, L coincide,
C, P "
D′, T "
C′, P′ O "
B′, D "

and the bars B C, D′ C′ make equal angles with A B in opposite directions; and the linkwork is one of those given by me in the *Messenger*.

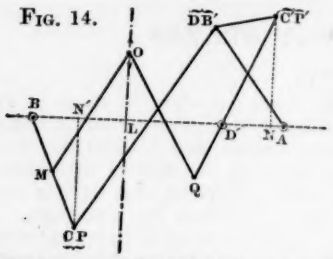
FIG. 13.



§ 14. The peculiar form of the fundamental linkwork employed in the last case may easily be seen to be really the same as was used in § 5. From the property of the equal inclination of the bars B C, D′ C′ to B A, another form of linkwork may be obtained which does not, strictly speaking, come under this group, but is an exceptional one.

C′ D′ is produced to any point Q and a point M is taken on B C such that B M = D′ Q. A B is fixed. The equal bars M O, Q O are added. Then O clearly moves on the straight O L per-

FIG. 14.

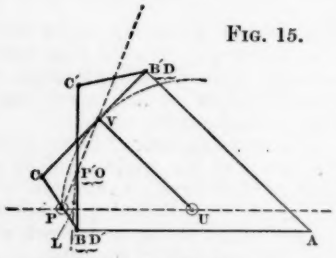


pendicular to A B, B L being equal to L D'. This linkwork was given by me in the *Messenger*.

§ 15. In the linkwork of § 11 replace the bar S T by the bar U V. Make

$$a=d,\ k=\frac{d}{a}=1.$$

FIG. 15.



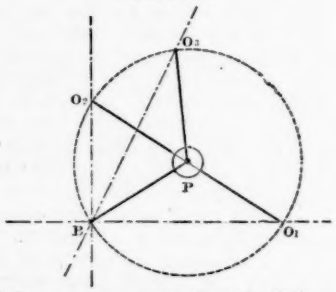
Then it will be seen that

B coincides with D',
B' " " D,

and the bars A D, A B become superfluous and may be removed. There then remains Mr. Hart's five bar linkwork. This is the only five bar linkwork, giving rectilinear motion that has as yet been obtained.

§ 16. In many of the previous cases the point O, which moves in a straight line, will be found to be connected to a fixed point through which the straight line passes by two equal bars. Whenever this occurs the motion of the bar containing the moving point is of the sort described by Professor Sylvester as "tram motion." That is, its motion is that of a bar sliding between two fixed rectilinear trammels, or, to present this motion in its fullest generality, the motion of a plane in which a whole series of points lying on a circle move each of them in straight lines passing through a fixed point. Turning to Fig. 16, if B P, P O_1 be equal bars and O_1 moves in the straight line O_1 B passing through B, then if O_1 P be produced to O_2 so that P O_2 = P O_1, O_2 obviously moves in the straight line B O_2 perpendicular to O_1 B, so that O_1 O_2 slides between the two straight lines B O_1, B O_2. In this case it is clear that any point O_3 attached to the bar O_1 P O_2, and distant a distance P O_3 = P O_1 from P, describes a straight line O_3 B through B, the angle O_3 B O_1 being one half of the angle O_3 P O_1. This greatly adds to the usefulness of the linkworks.

FIG. 16.



It is not suggested that the linkworks here given exhaust seven bar line linkworks; indeed it is obvious that many of them are susceptible of variations. Enough, however, has been shown to demonstrate the important part which the property of a quadrilateral combined with the principle of the conjugate image stated at the outset plays in the question.

I have strictly confined myself in this paper to the consideration of the rectilinear motion of a point. The principles involved, however, are applicable to many other problems, as, for example, the motion of bars every point in which moves in one of a series of parallel straight lines or in the same straight line. By means of the peculiar form of the fundamental linkage given in Figs. 6, 13, 14, valuable results in the reversal or multiplication of angular motion may be obtained, and a linkage of $2n+2$ bars may be constructed which will divide any angle into n equal parts. Some of these questions have been treated of by me in my paper in the *Messenger of Mathematics*, already referred to, which was, however, written before I obtained the general results here given. The extension of these results to other problems is reserved for future investigation.

CONTINUOUS RAILWAY BRAKES.

From "Engineering."

THE importance of the railway brake problem is at last becoming rapidly recognised, not only by railway managers, but in a general way by the traveling public also. During the last few years a great acceleration of speed has come in daily practice; speeds that a short time since were highly exceptional have become the rule, and those which were once considered apocryphal are now common. But such speeds as sixty miles and upwards an hour, can only be maintained with a permanent way and rolling stock as perfect as modern appliances can make them, combined with the most rigid inspection, and maintenance of both to the highest possible standard. And with the utmost skill in construction, and with the utmost care in working, accidents must from time to time occur, and accidents occurring at such high speeds are almost necessarily attended with disastrous consequences. More than ever, then, is the complete control of trains a question of increasing necessity, and the best available means of bringing a train from a high speed to a state of rest have to be found and adopted.

On almost all of the leading railways in this country steps more or less important towards this end have been taken. On several continuous brakes are wholly or partially in use, either for the purpose of regular working, or held in reserve for cases of emergency; but for the most part railway managers are feeling their way by experiment before they commit themselves to the introduction of a costly appliance, to which they must for some time at least adhere, after they have once decided on its adoption. That the utmost caution in arriving at a decision upon this important subject is not only wise but necessary in the interests of railway shareholders is evident, but we fear that in some instances, as on the Great Western for example, there is an indifference on the subject, and possibly to prejudice, perhaps to a dislike in bringing within the British railway circle what may have come into existence outside its limits, may be traced a part of the hesitation manifested.

We have so often in these columns considered the question of continuous railway brakes, and pointed out the requirements of an efficient appliance for the control of trains, that we fear almost to become tedious by repetition. But the subject is one of so great importance that it must be our excuse for reiteration. The main requirements to be sought for in selecting a railway brake which may be placed with confidence upon high-speed trains may be summarised as follows:

1. It must be capable of application to every wheel throughout the train, if so desired.

2. It must be so prompt in its action that no appreciable loss of time occurs between the time of its application, and the moment when its full power can be exerted throughout the train.

3. It must be capable of being applied by the driver of the engine, and at any desired point throughout the train.

4. It must be capable of application by driver and guard acting in concert, or by either independently of the other.

5. It must under all circumstances be capable of arresting the motion of a train in the shortest possible distance.

6. It must be so arranged that in the event of the failure of any one of its vital parts, such failure must record itself by the application of the brakes or otherwise; so that the train, if in motion, may be automatically arrested, and the existence of a defect be thereby made known.

7. It must, in the event of a train breaking into two or more parts, be capable of immediate automatic application to every vehicle, under all conditions.

8. It must be simple in its construction and in its mode of working, and not be more liable to derangement in any of its parts than any other portion of the mechanism on the train.

9. The duties it is called upon to perform must be done by the apparatus itself, and not by the addition of any auxiliary contrivance called in to aid an appliance which cannot of itself fulfill the necessary conditions.

10. It should preferably be inexpensive for first establishment, and necessarily cheap in maintenance, for if the latter condition be not fulfilled, constant watching and frequent renewals would be required, and the eighth requirement named above would not be complied with.

This list of requirements could be extended, but it embraces almost all the most important points, which are so evident as scarcely to call for any comment. The second condition abovenamed, ranks high in importance. It makes all the difference between the safety and destruction of a high-speed train, whether two seconds or eighteen elapse between the application of the brake, and the full development of the retarding force on the wheels. A striking illustration of this occurred about two weeks since on the North British Railway, with the fast Scotch express running from Carlisle to Edinburgh. On approaching Kershopefoot about 6 A. M., the driver of the train noticed fire flash from the rails four times at very short intervals. With most praiseworthy caution, he reduced his speed to about thirty miles an hour, and almost immediately after passed over a fog signal. Upon this he applied the brakes and brought the train to a stand within ten yards of a goods train that had broken down and blocked both lines. Only about twelve seconds elapsed from the time of passing over the last fog signal which alone had exploded, until the train was brought to a stand, and the distance run in this time was probably less than 300 feet. In this case, instantaneous action of the brakes alone saved the train. This incident gives also an illustration of the importance of the driver being able to control the brakes. Had he in this instance been obliged to signal the guard, a few invaluable seconds would have been wasted, and the collision must have occurred.

A railway accident which very recently took place on the Jersey Central Railroad fully illustrates the importance of the sixth requirement. On the 11th of November last, a passenger train running to the Communipaw Ferry, instead of pulling up at the platform, dashed on with undiminished speed through the depot, carrying away a portion of the goods office, and crossing the ferry pier outside, fell into the river, carrying its cars after it. The cause was as follows: the driver, who had been in the habit of relying upon the vacuum brake with which the train was fitted, attempted as usual to stop his train, but found that the apparatus had failed, and left him helpless at the critical moment. No warning had been given of this failure, no warning, in fact, could be given; the brake was simply powerless to act when called upon, and the results above narrated occurred. But if the brake had been able to speak for itself, and to call attention to its failure by automatically stopping the train, no such accident could have occurred.

To give a third and final illustration, this time for requirement No. 7. We described recently the Heely accident to the up-Scotch express, which, when running at a very high speed, parted near Sheffield, the forward portion running on, and the rear part being broken up and leaving the rails. The separation of the train threw every brake-block into action, pulling up the undamaged portion, and so reducing the velocity of the scattered carriages that—although the brake rigging was shattered by contact with the sleepers and ballast—the brakes had done sufficient work to bring the carriages to rest with but little damage, and without serious injuries to any passenger.

We have said that a continuous brake should be complete within itself, and not be dependent for the fulfilment of its duties upon any auxiliary appliances called in to help it, and we think this will be at once seen to be an important condition. For, if it be conceded that the driver—who must be the first to see an approaching danger—should have the means of at once bringing the whole brake power available to bear, it is obvious that any appliance is imperfect and incomplete, if he has to signal for cooperation from the guards. Auxiliary appliances, too, mean complication; they mean multiplicity of parts, increased chances of derangement, increased danger of failure at a critical moment, and they mean increased first cost and maintenance charges, though these latter are of comparatively small importance. The advantages of simplicity of arrangement and non-liability to accident are so obvi-

ous as to need no remark. Given different systems equally efficient in their action, and that one will be the better which requires fifty feet instead of 100 ft. of pipe, and one instead of two couplings, which is made of the least perishable material, or which is less likely to be destroyed. Thus, on the Pennsylvania Railroad—the whole of the rolling stock of which is fitted with the Westinghouse brake—almost innumerable robberies of the couplings occurred, attended with great destruction of the rubber hose, until the material was changed from gun-metal to cast iron.

It may be considered that all the requirements we have enumerated as being essential for an efficient railway brake, cannot be combined in one apparatus. We do not propose on the present occasion to discuss whether or not such a combination has been hitherto perfected, but simply record the fact that the whole of these functions are necessary for the control of trains, and that railway managers do well in hesitating to adopt any system which is unable to perform them. We shall, however, take an early opportunity of considering how far the various brakes which have of late years been brought forward, can fill the conditions named. Two of these systems which have perhaps been more prominently before the public than any other, are of American origin; the first is the Westinghouse automatic air brake, and the other is known as Smith's vacuum brake. The arrangement and mode of working of both these systems is sufficiently familiar to our readers to prevent us from publishing it here, and both systems figured in the brake trials at Newark in the summer of last year. Since that time, however, Mr. Westinghouse, and probably Mr. Smith also, has made considerable improvements in the details of the apparatus, and in its latest form, the automatic brake, after considerable experience with it in America, is now fitted on the more important trains upon the Midland Railway, where it has been, lately, as we have seen, the means of mitigating the effect of one very serious accident, and of preventing a second upon the very verge. The good judgment and foresight of Mr. Johnson in equipping the chief and fastest trains upon his line with this appliance, have thus received abundant practical testimony. Following this example, and acting with the same earnest desire of proving by the test of actual work, which is the best continuous brake at present available, Mr. D. Drummond, locomotive superintendent of the North British Railway, has recently had two exactly similar trains equipped, the one with the Westinghouse automatic, and the other with the vacuum brake, and he proposes, first by a series of experiment, and subsequently by the results of daily work, to test these two systems, and to satisfy himself which of them nearest fulfils the necessary conditions of apparatus for the efficient control of trains.

Carried out by so able a man as Mr. Drummond—who being entirely unprejudiced, desires to ascertain what is most adapted for his line, and to use that system which experience shows him is the best—these trials will have a value, which—though far more extended—those at Newark did not possess, and we feel assured that every one, including Mr. Westinghouse and Mr. Smith, will rest satisfied with the ultimate verdict of Mr. Drummond, which will be based upon the large and varied experience obtainable upon the extensive *réseau* of lines which he controls.

The circumstances under which they came about may be briefly referred to. Some two months ago, Mr. Drummond, having determined to settle to his own satisfaction the vexed claims for superiority, put forward by the automatic and the vacuum representatives, gave to each a similar train which was to be equipped in the completest and most perfect manner. After a short time the Westinghouse train was finished and ready for trial, but many delays occurred before the vacuum train was reported in running order. At last, however, it was finished, and invitations were issued to the leading railway men throughout the country. The Westinghouse train was taken out first, and ran from Edinburgh to Cowlairs over about forty miles of very fine line, in first-rate order, and the gradients of which are practically level. Some dozen stops were made in running out, and eighteen more in returning to Edinburgh, where the vacuum train was to be taken out for a first trial.

The vacuum train, however, did not appear. It was stated that the cause of the failure to come to trial was as follows: The representatives of the Vacuum Brake Company had borrowed from the Great Northern Railway two vans containing pumping apparatus to act as auxiliary appliances, and help out the ejector in producing a quick stop. One of these pumps had, it appeared, become, at the last moment, too much deranged to render trial possible, and hot axle-boxes were further reported as justifying delay. The further trial was, therefore, postponed. The vacuum train had a test run, and was reported to be in perfect order the previous Wednesday. The Westinghouse train was made up of nine vehicles, to all the wheels of which, as well as to the engine and tender, brake blocks were fitted. A tenth vehicle formed an exception to this rule. This was an experimental van, in which was placed a table carrying the indicating apparatus, speed guage, &c. On one side of the van was attached an electric signalling instrument, a similar one being placed on the engine, and communication was established between the two. A guage for recording the variations of pressure in the brake pipe was also in the van. As soon as any given speed, previously decided upon, was reached and indicated upon the speed guage, the signal was given through the wire from the van to the engine, the brakes being applied at the same moment that a return signal intimated the fact to the operator in the van. As soon as this return signal was heard, the time taken to bring the train to a stop, was ascertained by a chronoscope, and two diagrams were taken by Richards' indicators adapted for the purpose, the one showing the speed of the train at the moment when the brakes were applied (thus checking the speed gauge), the distance run before the train was stopped, and the retarding influence of the brakes throughout the period of their application. The diagrams taken by the second indicator showed the distance run before the full power of the brake was developed, while the time required for the brakes to be set on at the rear of the train was obtained by a second observer with a chronoscope, who recorded the number of seconds and quarter seconds that elapsed, from the falling of the brake pressure gauge to zero, to the stopping of the train.

Water from the same accumulator as that which actuates the speed-gauge, is in the experimental apparatus on the North British train, employed to work the two Richards' indicators already referred to. The motion for the drums of the latter is taken off the main pulley of the speed indicator, but reduced sufficiently through two worm gears. The ratios of speed between the pulley and the drum being exactly determined, the distance traversed by the train in making a stop can be accurately scaled, while the height above the zero line, at which the diagram terminates, gives also the speed of the train at the moment of applying the brakes, and thus the readings of the speed-gauge can be checked. As already stated, a second indicator forms a part of the experimental apparatus, and is used for taking diagrams to show the distance traversed by the train before the brakes are fully applied. The foregoing gives as clear an idea as it is possible to convey without drawings of the appliances prepared for testing the performances of the automatic and vacuum brakes on the North British Railway.

Their efficiency was thoroughly tested on Tuesday. On the run from Edinburgh to Cowlairs about a dozen stops were made and the results recorded, and eighteen similar experiments were tried on the return journey. Diagrams of each stop were taken, and the whole operation was completed in from twelve to thirty-five seconds, according to the time required to pull up the train. The element of uncertainty arising from misapprehension of distances run, of speeds attained, and so forth, are entirely eliminated, and moreover the character of each brake application is clearly shown in the diagram; so that not only can a great deal more experimental work be got through in a given time, but the results obtained are absolutely reliable, and the relative performances of different brakes can be compared with the utmost minuteness. It should be mentioned, by the way, that the speed-gauge employed on Tuesday recorded velocities slightly in excess of the truth, but this can be easily obviated; indeed the error corrects itself on the diagrams taken.

HOUSE DRAINAGE.

By Major-General F. C. COTTON, C. S. I.

From "Journal of the Society of Arts."

The paper I am about to read is not volunteered by me. It is written in furtherance of the effort now being made by the Society of Arts to elicit information on the subject of house-drainage, and to aid in its promulgation, by which it is hoped that the knowledge of this all-important subject may be made more general, and that this extended knowledge may so enhance the value of houses constructed on right principles, that builders will see the importance of being guided in their work by the teachers of sanitary science. Another result of a more general knowledge of the subject will, our Society hopes, be the enactment of better defined laws for the guidance of those who are entrusted with the public health.

In accepting the duty I have undertaken to-night, I am placing myself in the unfavorable position of addressing at once those who have made the subject of my paper their deepest study, and those who have still to be awakened to its importance, and are in need of the most rudimentary education.

It must, of course, appear to those who have been preaching on the same text for years, that recapitulation of their teaching must be unnecessary. But that this is not the case is proved by the entire disregard of all the first principles of sanitary science shown in the last year, both by the builders and the occupiers of many new houses, and that even in London, from which so much of the teaching emanates.

With this explanation I must crave the indulgence of all the men of sanitary science who are present to-night; begging them to accept my assurance that I do not presume to offer an education to them. What I hope for from their presence is the criticism that will lead to the correction of my paper. And in addition to that, I ask a full and free discussion of the points touched upon, which cannot but make the evening instructive to both sections of the meeting.

Though I shall limit my remarks to-night to the pipes and drains of a house, without entering into the requirements of the main sewer, I shall not, as the notice of my paper would imply, confine myself to the "construction of house drains." I purpose to submit to the Society such a *résumé* of what has been determined in sanitary science as will be a safe and useful guide to those who, having little or no knowledge of the subject themselves, are, nevertheless, aware that pure air is worth having, and that they would, if they could, obtain it.

This much is generally admitted, but there are comparatively few who realize what is the daily loss of health, and consequently of happiness, even by the well-to-do classes, from breathing contaminated air. Everyone, indeed, is ready to admit that the best remedy for the effect of a town life is an occasional visit to the moors or mountains, where the air is so exhilarating that it gives the idea of containing some stimulating principle not to be found in the air of cities; whereas there is nothing intoxicating in the atmosphere of the most favored regions. It is simply pure, as air ought to be; and so those who breathe it have the health, and vigor, and buoyant spirits that were their birthright.

It is in our houses—more especially in our town houses—that the air is in an abnormal condition, as Dr. May explained the other day to his neighbors at Kensington, who complained of lassitude and debility from the "relaxing climate" of the locality they lived in, that their languor arose from the loss of vital energy, the result of breathing air tainted by gases from their own foul drains.

It is this depressing effect of impure air that accounts for the "nine sinkings" said to be felt by London ladies between their waking hours and bed-time. In this there is no affectation of distress on their part. Follow these ladies in their Highland tour, and you will find them satisfying a healthy appetite by three hearty meals a-day, and craving for nothing more.

And if we watch the effect of these depressing gases on the poorer classes, who can have no change of air at any season, we must follow them to the fatal gin-shop, where, poor souls, they find an exhilaration which seems to them worth having, however evanescent, and however fatal in its after-consequences.

I am induced to insist upon this never-ceasing loss of vigor from impure air, as it comes directly home to everyone at all times; since it appears to me that the reports of occasional visitations from typhoid fever or diphtheria only stagger people for the moment, and being too terrible to dwell upon, they do no more to correct the defects in our sanitary system than public executions did to lessen the amount of crime. In the depression that results from living in an impure air, all our functions are crippled, and we have none of that elasticity to throw off disease which we have when in perfect vigor. Like the weakly plant, the blight can take possession of us unresisted. This is admitted in a way, but it is not fully recognized; or the great effort, both of rich and poor, would be to purchase the purest air that could be bought, according to their means, looking to sanitary laws as the only safeguard in the artificial life they are leading.

There is no doubt that some of our first efforts at refinement did anything but place us in a better sanitary condition, notably the introduction of closed sewers, and the closet in direct communication with them, which led to evils that are still only in progress of correction. Indeed, it is almost exclusively this refinement that affords us the subject we are to discuss to-night. On the other hand, giving them up would throw us back to barbarism.

When the danger arising from this was first looked into early in the century, it became apparent that some alteration was necessary in the sewers, for they carried off the waste so slowly and uncertainly that they virtually distilled the decomposing mass, and returned all that was poisonous in a gaseous form, most difficult to deal with.

We are indebted to Mr. Roe for the first effort to correct this, by altering the form of the sewer, so that a much smaller quantity flowing would have velocity sufficient to keep the passage clear. This was a most important step, and led to what was done immediately afterwards by Mr. Edwin Chadwick, who, realizing fully the danger of allowing the sewage to decompose within reach of inhabited places, devoted his wonderful energy to convince the world that the only safety was in expediting its passage from its source in the house to its outlet in the air, wherever that might be done without fear of further mischief. In his investigations, that great reformer convinced himself that, under a perfect system of drainage, the sewerage of all London might be put out of harm's way before it began to liberate its gases. Whether this was attainable or not, it led to an entire change in our whole drainage system, the importance of which cannot be over-estimated.

I am sure I shall be forgiven if I occupy the meeting for a few moments, while I mention the services rendered by Mr. Edwin Chadwick, who, most unfortunately, is, by a rule of our Society, absent from the Council this year, when one of his own special subjects will be frequently under consideration; and I must at the same time express regret that we are, from the same cause, deprived of the advice in our Council of Mr. Robert Rawlinson, whose guidance would have been invaluable.

Mr. Chadwick was not by profession an engineer, and he had the difficulty to contend with of the country not being educated up to his mark. No Government can go far a-head of the people's education, so our great sanitary reformer was a difficulty to the Ministers of the day. Even the engineers could not take up his views, one eminent man of that profession having been heard to say, in irony, "Chadwick would drain all London through a gun-barrel." And although he brought to bear upon his subject thorough knowledge of it, ability of the highest stamp, and enthusiasm that nothing could curb, he had, unfortunately, to leave many important suggestions to be carried out at a later day. It must, however, be no slight satisfaction to him to find an engineer so pre-eminent in sanitary science as Mr. Robert Rawlinson, dedicating to him, as "the chief promoter of modern sanitary works and appliances," a collection of the most able

papers and letters ever published on the subject.

Leaving out of account for the present the effect of sewage soaking into the ground, and contaminating the water we may need to draw upon for our use, all that is poisonous from the sewers comes to us in the shape of gas. This is produced by the organic waste from our houses being decomposed, the decomposition being aided by the addition of water, and expedited by heat, stillness of the air and stagnation of the fluid mass being highly favorable to this chemical process. Of the exact nature of all the gases evolved in this terrible retort we are not yet aware; and when the complication of the seething mass is considered, the variety of its ingredients, and the different proportion in which they are thrown together, its ever varying temperature affecting the liberation and expansion of the several gases, each according to its own laws, it cannot be expected that, even with the high talent engaged in the research, we shall, for some time to come, unravel its mysteries.

If it were necessary that we should master all this difficulty before we took steps to correct the evil, we might well be disheartened in our investigations; but, thanks to those who have watched the effect of these mixed gases, we have evidence enough that all we do to reduce the per-centage of them in the air, is a clear gain to human life and health.

If there are any still left who pride themselves on having found a seeming paradox or puzzle in the calculations of sanitary science, and would have us wait till it is explained, they are turning their talent to a very poor account, and have not much chance of a patient hearing in the present day.

I have said that all we have to fear is in the gaseous state; we cannot prevent decomposition liberating the elements in that form. We must, therefore, do all we can to remove the material from our home as rapidly as possible, by the most suitable means at our disposal, the vehicle for the present used being water; which, although it affords an extremely cheap carriage, and is very convenient for our purpose, is, nevertheless, not without its danger. Water in certain quantities aids in the decomposition of our refuse, and supplies some of the ingredients of the noxious gases that we dread. Great efforts have, therefore, been made to avoid the use of water, and several so-called dry systems have been introduced and tried, in some localities with success; but I need not now enumerate them, as they are foreign to our purpose to-night. We may, however, wish their promoters God-speed, while we make the best of the means now at our disposal, which must, under any circumstance, be in use for many years to come, even though any safer system should eventually be perfected.

I must be allowed to say that there is something very attractive to me in Captain Liernur's idea of everything solid or gaseous being drawn inwards and onwards to a distant vacuum, the solids to be dried and utilized, the rest to be evaporated by fire. But we have nothing to do with this at present; water is our vehicle, and we must so use it that it shall lessen, not increase our danger. To ensure this, the essential is an abundant, and, as far as possible, a constant supply.

We will now consider the appliances by which we turn to account this water-carriage, the most important of which are what are usually called the house-drains, those which collect the discharge from all the pipes and convey it into the sewer. In large houses there are often several of these, but, for convenience of description, I will use the singular number.

In detached houses the house-drain may always be led clear of the building, and possibly no house in future will be placed at the disadvantage of having it under the basement. Many old houses have this fault, some no doubt in consequence of the house having been extended over it. In all such cases it would be well to correct this objectionable arrangement at almost any cost, since the danger of the position is extreme.

In houses built in streets this faulty system constantly prevails. It has been the general practice to have the sewer under the street, and as the offices and all that is unsightly lie at the back, the drain of necessity has to be laid under the house. Where the lines of houses are very near together this is unavoidable, but it raises a question whether in

building in future this ought to be allowed.

I am no advocate for tyrannical Government; but I think that when the owner of land has to make his choice, whether he shall continue to cultivate it, or raise a crop of houses on it instead, the Government may fairly insist upon his not building at all, if he will not be guided by sanitary laws; and I would undoubtedly define the minimum distance at which lines of houses should be placed, as well as the disposition of the drainage, on which the sanitary condition of the new street will in the future so materially depend.

We have only to consider the nature of the house-drain, and the evils resulting from its being imperfect, to realize the importance of its not being under the house. This vital artery of the system, having to carry the whole refuse of the house, and deposit it in the sewer, will contain two currents, one of fluid and solid matter descending, and one of sewer gas ascending; for it is a neck of the great retort, and will be supplied with gas from it, do what we will to divert it by ventilators along its course, as is now so generally and so advisably arranged for.

The appliance in most frequent use for this drain is a stoneware pipe, which is made in short lengths, necessitating even in small houses very many joints. If these joints and the junction with the sewer and the house-pipes were water-tight and gas-tight, it would matter nothing whether the drain were under the house or not. But if the material fails from any cause, or a joint is broken, the consequences are an escape of either gas, or sewage, or both, that will in time saturate the soil surrounding it. If this takes place when the pipe is clear of the building, it will be detected, and may be comparatively easily corrected. But if the pipe is below the basement, the first cause of suspicion that all is not right may be in the illness or death of an inmate of the house. And as the pipe cannot be examined without taking up the basement floor, its actual condition will never be inquired into by the occupants of the house, unless they possess an amount of energy very unusual.

Back drainage, as it is called, when the drain from the house leads to a sewer at the back, has other important advantages, besides the accessibility of the drain, and the comparatively little mischief it will cause if it is imperfect. It will, in most cases, be shorter by the whole depth of the house, and consequently have a far more rapid fall, while the whole sewer-system can be opened at any time without interfering with the street traffic. This better mode of laying out building land has been adopted here and there, but there are great towns rising all round London, and, indeed, all over England, where the old mode is continued.

I must notice here the mode insisted on by Mr. Rawlinson of laying out house-drains, where curves have hitherto been used. He would have the whole system in straight lines, with man-holes at all the angles; by which arrangement the drains can be cleared without being broken up. When the length of any line is great, a man-hole will be made at the spots necessary to bring the whole within reach of those engaged in cleansing it.

We will suppose our drains, then, to be under the house, in considering its requirements, and with reference to the size, return to the principle that guided Mr. Chadwick, namely:—That no drain or pipe intended for the passage of water and its burden should be larger than the maximum it will be called on to convey, without being subjected to undue pressure, in order that a favorable velocity and scour might be ensured, and the surface of the pipe kept as clean as possible thereby. The required size for each pipe will be determined by the supply and the fall that can be given to it, experience having led to the conclusion that it is well to make allowance for house-drains not being more than half-filled with their maximum charge, the fact being that even a pipe of six inches internal diameter will carry all the drainage of a tolerably large house. I mention this only to give a general notion of the size, for the actual size in every case should be decided on the spot by a qualified engineer, who would have all the peculiarities of the site before him. In all designs for house-drains it must be considered that, although we have, as compared with the sewer, only feet instead of miles over which to ex-

pedite the current, we must not lose sight of the fact that any material which will decompose may find a lodgment in our pipes, if the stream is not rapid enough to lift it and transport it. The first consideration is, how it can be kept clear, even though the supply of water entering it may not be constant. The essentials will be, a fall that will give a good velocity to the current, even when the depth of the flow is small; the most polished surface that can be obtained, and the best fitting joints, not only to prevent escape but to present no obstacle, however small, to the passing current, lest the detained particles should collect others, and so form a reservoir of the sewage, in which, when there happens to be little or no flow in the pipe, decomposition will take place, and a private distillery of poison will be established on the premises.

Glazed stoneware is a good material, as it is not acted upon chemically by the gas or sewage; and its surface being highly polished, and not capable of being corroded, it will offer less resistance to the fluid than would be the case with either lead or iron.

The objection to stoneware is the difficulty of perfecting the joints, and having them so true as to offer no impediment. A vast variety of joints, and all sorts of lute and packing, have been suggested, the practical difficulty being to form a perfectly tight joint which is not so rigid that on the slightest movement of the pipe it would cause the ware to break. To obviate this, pipes are very frequently laid, trusting the safety of the joints to a packing of clay, which, of all the materials in the world is the most treacherous. My experience, in a long life of engineering, is that clay is unfit for anything but the fire; it is admirable in the hands of the potter, but, unburnt, it is utterly untrustworthy. When wet, it is plastic and adhesive; water-tight, pleasant to work, and satisfactory in appearance, but on drying it shrinks and cracks, loses its hold, and its every characteristic is reversed. A house founded on clay may stand any number of years, and settle in a dry summer after all. A clay puddle-bank has been the cause of the most terrible disasters, and as a lute for joints it may be clay one day and powder the next.

As it would be utterly impossible to do justice, in the selection of the best material or appliance, amongst the numberless clever inventions of the day, I had resolved to offer no opinion upon any; but I am inclined to break that resolution, by recommending a pipe which from the form of its joint, and the perfection of its manufacture, I do consider one of the most valuable additions to sanitary appliances ever brought to light. I allude to Mr. Stanford's joints, as they are made by Messrs. Doulton, which from their spherical form admit of some movement without opening; and by the skill with which they are made, are really as perfect as the ground-glass stopper of a phial. It is almost impossible to guard against careless workmanship, but from the rapidity with which these pipes can be laid, and the facility in laying them, particularly where the slope would help to ensure the joints being closed, superintendence of the work is simplified to the utmost, a point of great importance when the sanitary officer, with his many duties, is held responsible.

Whatever pipes are used, they ought to be lodged on concrete, so thick as to secure them against the operations of rats, which never seem to give up the hope that they may undermine a pipe, and when it settles, have access to the luxuries it contains. In the case of pipes being used, the joints of which can not be trusted, I know no way of making them secure, but by imbedding them entirely in concrete. Pipes very inferior to those now used were employed in the old city of Broussa, in Asia Minor, which, thus embedded, bore a great head of water, supplying fountains in every house. Some of these remain in use to the present day.

When laid, this very important pipe is buried in soil of some sort, the floor is closed over it, and nothing more is known of its condition for any length of time. It is fully admitted that, before this is done, the work should have been inspected by some one deputed to report upon it to the Local Board. But it is urged that, where much building is going on, the Boards have not staff enough to watch the work, so as to be able to say confidently, not only that the design is satisfactory, but that the materials are

suitable and good of their kind, and the workmanship faithful. Yet the drain, on which so much depends, may entirely fail if in any one of these points a fault may have been detected.

This brings it to a question as to whether we are to look to local government for security, and pay for it by higher rates, or whether we must take the chance of all being safe below us.

Before we leave the drain we must inquire what has been used to cover it. Is it tolerably free from organic matter that may rot and form gases, independent of the sewer, but, nevertheless, unwholesome? Does any one look into this—either public functionary or the would-be occupant? Certainly not the latter; sanitary knowledge has not yet led to that. And yet the value of the house, as a healthy home, in no slight degree depends upon it.

Our object being to elicit information, I would ask here whether there are still low-lying lands being filled up for houses to be built over; and whether the old system of raising the land economically is still adopted, of merely setting up a black board, with the words on it, "Rubbish may be shot here?" Where land is dear, rubbish cheap, and great interests are involved, have we a local government that will see what this rubbish is that is to be built upon, and prohibit the use of all that is dangerous?

The answer to this will, I am sure, differ as much from all parts of England, as the reading of the Local Management Act differs, by the several officers who were good enough to come to our Conference the other day. Even if the Local Boards have not staff enough to watch the building while in progress, they could, I imagine, prevent so radical a sanitary fault as may result from indifference on this point. In the meantime, I can confidently assert that many miles of houses have, even of late, been built, in which sufficient care has not been taken about the material used for filling in. Even the fine beds of gravel have in many places been injured as sites by this; the gravel has been sold, and the sand below it used for the mortar of the house, and anything that came to hand has formed the surroundings of the drain.

It may not be known by those of my hearers who have not examined such matters, to what extent this may affect a house. The fact is, that our walls are sufficiently open in the center to form flues for air or gas, and when our fires are lighted in the winter they act as pumps, and very powerful pumps, to draw the air and all that is in it from below the basement to the attic; with a delivery between the ceiling and the floor of every story, where there is neither plaster nor paper to seal it up. If we have a rotting mass below the basement floor, we have a supply of gas in the best possible position for these pumps to draw from. With reference to this, it would be well if every wall had, what some few are built with, a water-tight and air-tight course a little way above the basement, the intention of which is to prevent the damp from rising,—this would have a very important effect in this respect. Not that this would save the basement floor from inroad of this gas, but it would, in some measure, check its distribution through the house. If such filthy material as we are speaking of is used, a concrete covering of the whole is essential.

Now that we have so many really able and earnest men watching the builders, as much as their multifarious duties admit of, we may, I hope, feel confident that nothing so infamous will ever occur again as Dr. Whitmore found in Harley-street, where some thirty house-drains had never been led into the sewer, and had been for years pouring their contents into the soil.

But until some system is adopted that will induce builders to make this critical part of a house secure, we can never consider ourselves sure that we have the air of our rooms free from taint, from some flaw or other.

It will be for future consideration whether an extended supervision by the Local Board, or penalties on the builders for negligence, when discovered, certificates by accredited engineers, or any other better means can be devised. All we can do at present is to urge that the subject may not be dropped till it is thoroughly investigated, and the abuse corrected.

The connection of the pipes supplying the house-drain will be defended to a certain degree by one of the many in-

genious traps that have been invented for the purpose, on the merits of which I will not venture an opinion. It is well established, now, that the water in any trap will absorb gas, and, if time is allowed, it will pass through it. It is not, in short, the security it was once supposed to be; but when it is considered that what we are doing is to use every means to divert, exclude, and dilute the gas that is ready to enter the house wherever there is an opening, it is evident that a trap is one of the means not to be neglected where it can have any effect at all, and a well-constructed trap with fresh water passing through it frequently is of very important service, always provided that it does not lead to an accumulation of gas behind it. If it did so, it would do more harm than good, for then, sooner or later, the gas would force its way through in a concentrated and consequently a most poisonous state. Indeed, the whole point seems to turn upon the state of concentration the gas is in; and the sewer engineer is acting on that supposition when he makes an opening every hundred yards, in the hope of the gas escaping in so mild a form that, when mixed with the air, it will be harmless. It would be well if we could ventilate the house-drain as simply, but that would bring us too immediately in contact with the gas, which even in the open street is bad enough at times.

Where the house-drain can be continued to a higher point above the last connection with it, as is sometimes the case on a hill-side, an outlet may be made there for its ventilation on the level of the ground, if there is nothing to be injured by it. But in town houses the highest point or head of the drain will be where the highest pipe from the house enters it. And here the gas must be allowed to escape by a tube carried high up the roof, away from either attic, window, or chimney, lest a draught should draw it into either. If gas would take advantage of such an outlet, and rush up it rapidly at all times, ventilation of the drain by that means would be simple enough, but gas has no such accomodating tendency. It has the peculiar faculty of diffusing itself through the air and within other gases, but it seems to keep its cloud form when not under pressure, and to move with a rotatory motion, a remarkable illustration of which is seen in the cloud-form adopted by steam as soon as it is clear of the funnel of the locomotive.

Without going into the complex nature of gases, of which I am quite incompetent, I only allude to these peculiarities to give some idea of the slow progress gas might be expected to make in diffusing itself along a thin pipe, from which we see the advantage to be derived by the use of a tube of large diameter in ventilation. When the air is at rest, and there is no difference of pressure between that in the sewer and that at the head of the pipe, we shall only have the advantage of this diffusion, greater or less, according to temperature. But anything that alters the pressure in the sewer or drain, will cause another movement in the gas. A sudden gust of wind, entering by the sewer ventilator, may clear the whole pipe in a moment; and if the drain become warmer than the air, there will be a current established upwards. A passing wind across the head of the pipe is found to draw the air or gas out more rapidly; in short, the gas will always be moving in the tube, sometimes very rapidly, and the tendency will generally be in favor of an upward current. We have, therefore, in a simple pipe, a great auxiliary in our effort to get the gas away. A ventilator in that position should never be omitted, and in no case could a pipe of less diameter than four inches, be trusted. Many suggestions have been made to insure a good upward draught in the pipe, which I shall not discuss here, merely saying that it is the object to be sought for.

We will continue our consideration of the house-drainage system above the floor of the basement. It is thoroughly established that no pipe in the house should be actually connected with the house-drain excepting the soil-pipe, which carries all that cannot be delivered in the open-air without offence. The rain-water, the waste from the several sinks and from the baths, can all be discharged into the open air, and be led into a grating with traps below them; they should on no account have a direct communication with the drain. It would seem impossible to many of you that any mention of this very obvious

fact should require further notice; but I can assure you that if you will look into hundreds of houses close at hand, you will find that the builders of them are altogether ignorant of this. I say ignorant, because there can be no earthly reason why they should not act upon the knowledge, if they possessed it, seeing that the change from the old system to the new, would not, in this particular, cost a shilling more in the building of a house of any size.

The pipes from all other sources than the scullery, flowing into the open grating, will be rather a gain to the house-drain, helping to scour it, but the scullery supply will be loaded with grease, which, when it chills, is difficult to deal with, and it would be well if it could be all deposited before it reaches the drain. Many clever devices have been invented to effect this, but none of them can be left to take care of themselves. If the grease is caught, as it ought to be, it must be removed by hand, or the drain will become foul and offensive, and be the cause of mischief. It is recommended that a stream of hot water should be turned into the drain occasionally, to melt any grease that may adhere to it; but if this is done, the sudden increase of heat will cause the gas to expand, with every probability of its forcing the trap above; while the grease will only be carried into the drain, and there be deposited out of reach. The clearing of the scullery-pipe, and the prevention as far as possible of grease in the house-drain, should never be overlooked.

All the waste from the baths and such like may be turned into the rain-water pipes, which may be of iron, and so that they keep the water from making the wall damp, and end about a foot from the ground; they require no special attention. In the country this arrangement will, of course, be modified where it is an object to save the rain water; and it would also be necessary in London, if the water did not contain so much that is objectionable.

The chief anxiety of the house system will be the soil-pipes, and the fewer there are of them the better. The soil-pipe should never be closed at the top, it should be extended upwards, whether over the roof or through the roof at its full size, and terminate, like the other ventilator, where its discharge of gas can do no harm. It will, under this arrangement, be a permanent ventilation, and an occasional waste-pipe; and although gas would be held in it in a very diluted state, still its condition depends upon so many influences, that it must always be considered dangerous. If no water has passed through the trap in the house drain for some time, it may be receiving a heavy charge from that source; there may be fumes from its own unclean state, or from gases generated in the traps that are in each closet drain that joins it, which will rarely be filled with quite clean water. This pipe ought not to be made of lead, if a better material can be found, because the gas acts upon and destroys it rapidly. If it is of lead, as it very generally is, it ought to be made without solder, as that is still more rapidly acted upon by the gas. A good lead pipe, however, will last a long time, and if outside the house, its condition can be watched. Stone-ware can be used when built into the wall, and if Stanford's joints are employed ought to be secure. There will be no soil-pipe inside the house when architects have completed the study of sanitary science.

Where the branch from a water-closet joins the soil-pipe there will be a trap; the pan itself forming another trap, there will then be that greatest of dangers in any system of drains, a space enclosed between two traps, in which gas may become concentrated to any amount. There is little doubt that gas has been collected in these spaces that has been most fatal. I was told of a case the other day, where a housemaid, opening a valve that had been closed for some time, became insensible from the load of gas that was discharged from it. The quantity of gas generated in this space from moment to moment is very small, and it is only essential that it should have an outlet to the air. In case of its opening near a window, a short length of pipe may be required, but this will not usually be needed, excepting when the closet is away from an outer wall.

It will be seen, as I said when speaking of our house-drainage system, that the whole and sole cause of the danger of concentrated gas entering our houses is from the use of the water-closet.

Their position in a house ought, therefore, to have the architect's greatest consideration. These closets should either be projections or towers, cut off from the house, or failing the possibility of that, close to an outer wall, without which neither the light nor the ventilation essential to their purification can be obtained. It will be well to remember that, if the closet is hotter than the outer air, the tendency will be for the gas in the soil-pipe to force the trap when the valve is opened. In winter there must be a difference of temperature; but I mention the fact to show the advisability of not allowing the closet to be more heated than is absolutely required.

Having done all in our power to exclude sewer gas from our houses, we have still to purify the air of the rooms we are living in, by draining off that which has been vitiated by our own exhalations, and by the combustion which produces artificial light and heat. The air that has been injured by these causes is unfit for respiration, till it has been restored to a sufficient degree of purity by the admixture of fresh air, which, of course, implies a constant current of air out of the chamber to make room for the fresh supply.

The quantity of air polluted by each individual breathing, and the quantity demanded for illumination and heating, have, of course, all been tabulated, and tests determining the most minute quantities have been brought to bear upon the investigation, one result of which is to show that the chemical difference betwixt pure air and air unfit for respiration is very small in amount, showing how necessary a constant change must be. Dr. Angus Smith gives the difference of only three per cent. of oxygen in pure air and in air that is unwholesome, while the quantity we require in an hour is said to be 3,000 cubic feet for a single individual. I need not go further into quantities to make my hearers wonder how we can find air enough to breathe in crowded and brilliantly-lighted rooms in winter, when there is no apparent inlet.

In summer, when the windows can be opened, we trust to an incessant diffusion from without, and to the almost constant motion in the air from changes of temperature, near or distant. But in winter, when our rooms have to be kept warmer than the outer air, we at once meet with a difficulty in obtaining the current into the room, without producing a chilling stream, undeniably dangerous to health. This danger being more palpable and instantaneous in its effects than the ills arising from breathing tainted air, induces us to take all possible means for preventing it. The door is surrounded with india-rubber, and there are sand-bags on the window-sills, but still the fire burns brightly, and the air is rushing up the chimney; it must come in from somewhere, and in large quantities too. It would be well if we took more trouble to inquire from whence it is supplied. It must enter, for the most part, by crevices in the floor, and inlets so small that they are not observable; indeed it has been demonstrated that air can find its way through the ordinary stock brick with very little pressure. The sources are as various as the directions in which the currents flow; this only being certain, that what does not come almost directly from the outer air is more or less impure.

Mr. Rawlinson says of air brought through flues, "it has the life taken out of it;" then what of air that has been brought by our fires from below the basement through the intricacies of an imperfect wall, and has expanded between the floor and the ceiling of the room below, loaded as that space usually is with chips and bits of plaster, cobwebs, and dust of all sorts? These are as bad flues as air can pass through, and there can be but "little life left in it" when it reaches us.

Even though the house-drain may have been well covered, and decomposing rubbish has not poisoned it at its source, as will frequently have been the case, those who do not so persistently close every possible entrance for fresh air, may still rest assured that in the winter, when every door and window is shut, a good deal of air in their rooms must come from sources that make it very impure before they breathe it. The question of course is, how fresh air, cold as it is in winter, can best be brought into the room without flowing in chill streams upon its occupants. Numberless inventors have worked for this end; among the best results has been the

Galton stove, which seems to me admirably adapted to its purpose. The outer air is led around this stove in such a way that it is warmed and not burnt, and though it enters the room near the ceiling horizontally, it does not, on account of its warmth, begin to fall immediately, as it would if it were cold. Its passage has been traced, and it is found to circulate in the upper part of the room, descending gradually as the fire abstracts the lower stratum, giving the inmates the benefit, before the fire withdraws it from the room. This stove must also be economical in fuel, as much of the heat that would be lost up the chimney, in an ordinary fire-place, is utilized in warming the air that enters the room. But a Galton stove is not at the command of everyone, and we want relief for millions who are living in semi-suffocation.

This, I think, we have in the mode of ventilation brought last year to notice by Mr. Tobin, which was to let the cold air enter by a vertical current, so that it should not fall into the room till it had diffused through the upper stratum. If this principle is correct, it is, I maintain, of extreme importance, because it can be applied at once, by means the most simple and inexpensive, while its use may be extended to buildings of any size.

To show how this suggestion can be utilized at once, I need only refer to General Scott's mode of supplying fresh air to his children's school room. He bored a line of holes in the door of the room, and turned the current upwards by a guard in front of them, by which simple means he obtained the vertical current required. No draught was felt, the air became warmed in the upper part of the room, and eventually was drawn from the floor-level up the chimney. I would ask how many stuffy village schoolrooms there are, that might be changed from being insufferable to sufferable by this simple means?

In a room close to the one we are in, an appliance even more simple has been in use for some time, with very good effect; the lower frame of the upper window-sash being cut, so as to allow the air to come in between the frames, where it takes a vertical course long enough to prevent its falling in a cold stream upon the heads of the inmates of the room, as cold air does when it comes at an angle and falls by gravity. This upward current arises from a similar cause that keeps up a fountain's play, and the extent of its action depends in both cases on the velocity of the stream, at its exit from the orifice for its escape.

There are many other simple ways of treating windows to induce this current, and many more will be suggested when the principle is understood. But I must refer to an admirable trial that has been made of the principle in a ward of St. George's Hospital, by Mr. Brudenell Carter, which has been in use for more than a year. The air is let into the ward by perpendicular tubes, supplied by horizontal tubes open to the air. The upright tubes open above the heads of the patients, who feel nothing of the cold air, though it enters very near them. At the time I had an opportunity of examining the ward, there was a fire in the room, and the thermometer stood at 68° at all heights, from the floor to the ceiling. The air was strikingly pure compared with that of the next ward of the same size and character, but not so treated. Indeed no one could pass from one ward to the other without feeling that it was a complete success. As this ventilation has now had a good trial, I wrote to ask Mr. Carter, whether he was still satisfied with it. His reply was this:—"I am still entirely satisfied with the ventilation, both at St. George's and at home. Nothing could answer more admirably: and I have had its application in my own house considerably extended."

To have this ventilation in perfection, it is evidently necessary that there shall be such a current from the room as will ensure a considerable velocity in the stream entering. With a fire in the room this can be ensured, by stopping in the usual way other entrances that would cause draughts; but it is a question how this can be done, when there is no fire to induce a current. If the chimney flue is open, as it ought always to be, there will be an upward current, as the room becomes warmer than the outer air, and to this extent the system will work automatically when the room is inhabited; but whether the volume entering will always be sufficient under these circum-

stances I am not prepared to say. Mr. Brudenell Carter, however, finds no fault with the ventilation at any season; at all events, as it now stands, it is undoubtedly valuable when most wanted, *i.e.*, in winter. On its first being brought to notice, it was asserted that all the cold air coming in did not reduce the temperature of the room, an assertion which led, at the moment, to a doubt being thrown on the whole suggestion. But it appeared that, as the loss of heat was entirely in the upper part of the room, where the air would have been over-heated, there was no loss to those who occupied the ward. Indeed, the thermometer standing so high as 68°, with only one fire in the room, went far to prove there would be no reduction in the mean temperature.

What I would ask of this meeting on this head is, that some means should be suggested for causing a sufficient current out of the room at the floor-level, to induce a rapid supply through the tubes when there is no fire in the grate to ensure. When that is established, this system will be made as perfect in summer as it now is in winter.

One great fault found with all currents brought from the outer air in London and other large towns is, that it brings in soot and dirt; and an undeniable objection this is, so objectionable that I am induced to notice what I consider by far the best suggestion yet made to cure this evil. I allude to the arrangement shown in this diagram, in which the air entering is made to impinge on the surface of a tray of water, which, as it becomes loaded, can be emptied and replenished, a most important step, I think, in the growth of this system, which I cannot but hope will be of very general use when once thoroughly understood.

As we have ample reasons at all times to exclude sewer gas from our homes, I have not yet alluded to it in its most formidable character, as a nursery and vehicle for those fatal diseases which are classed as preventible, and well-known now as dirt diseases. The arrangement of the drains and pipes ought, if thoroughly carried out, to secure each house from its own impurities; but such is the character of some of these diseases that your own vigilance will not protect you against your neighbor's negligence. And a most important question rises, as to how those who have set their own house in order can be secured against the ignorance or apathy of those surrounding them. The law of the land ought to save a man from being drugged by poison brewed for him by anyone. Are there such laws in existence now as will protect him? It would appear from the various opinions given by the Officers of Health who attended our Conference, that the Acts of Parliament on which the public health depends, are capable of different readings by those for whose guidance they were passed. But before we go into the administrative, let us see what good results we can claim from our sanitary laws in the condition of the many lines of houses now being built in the extension of London. It is almost universally admitted by the local officers that, although the house-drains are nominally laid under supervision, the staff of the vestries is not strong enough to admit of the work being actually watched. In other words, no man can feel secure that his chief drain is not leaking, and forming a cesspool under his house. This fault may exist in one or all of these new houses. I will now enumerate others actually in sight.

There are two rain-water-pipes, both of which join the drain, with the nominal protection of a trap at the head of it, which has no ventilation. All the other waste-pipes of the house join either the soil-pipe or the drain. It will be observed that there is not an absence of ventilation in this system above the head of the house-drain; on the contrary, there is a passage for sewer-gas into all parts of the house by every pipe. And as the rain-water-pipe and the soil-pipe are of iron with open joints, what does not escape at their head, just on a level with the attic windows, steams from the joints around the windows of the rooms below; while the space beneath the pan of the water-closet, the trap connecting it with the soil-pipe, is left unventilated, a most fruitful source of danger. This list of faults does not, I fear, leave us much to show as good resulting yet from sanitary teaching.

There is one danger from sewer-gas almost more to be dreaded than any other. Its getting into the cisterns, where, from the tendency of water to absorb gas, it will become impregnated and poisonous,

owing to the waste-pipes from cisterns being in communication with the drain. This was a very common fault formerly, but is being rapidly corrected now, and sanitary supervision, may, I think, claim its having arrested this most certain cause of danger.

Our sanitary laws are also doing much to correct the water-supply; but where the water is obtained from wells in towns or near buildings, there is always the risk of contamination from leaks in the drains and sewers. Where this is the case, the effects are often fatal. The distance to which the poison may be conveyed was shown in the effect produced on wells supposed to supply the purest water to country houses, when, during the spread of the cattle-plague, the carbolic acid and other pungent disinfectants used in farm buildings near could be detected in the drinking-water. One case came under my own cognisance, where so much store was set by the water of a certain celebrated pump that glass pipes were used to insure its virgin purity, the strong carbolic taste proved that it must always have drawn upon the cattle-sheds for a part of its supply.

Although very much more interest is taken in sanitary subjects than formerly, and numbers of extremely able men are making a study of the science, and giving their knowledge to the world, still the new light has not reached our builders, or, I fear I may add, many of our architects; nor are the existing laws so carried out by pains and penalties as to enforce their learning. Houses in hundreds are still being built, in which every sanitary law is violated. The real remedy for this is, of course, sanitary education; but it must reach the point of being possessed by the public generally before it will affect the builders. As soon as houses are valued for the care taken to insure their healthiness, then only will the builders' attention be diverted from the decorations to the drains. This education ought to be proceeding rapidly, as hardly a day passes that volumes are not published on the subject from the ablest pens. Not only are our first engineers engaged in this teaching, but to their honor be it said, no class in England are more active or more earnest in the work than the medical profession. And as they carry their knowledge from door to door, and enforce their teaching with authority, we may look to them in no slight degree for the people's education. Their efforts, supplemented by letters in the papers, lectures, and the advertising sheets of new appliances—one great disseminator of such knowledge—are all, no doubt, contributing to form this education.

THE APPLICATIONS OF ELECTRICITY TO THE PROTECTION OF LIFE ON RAILWAYS.

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It is proposed in the following discourse to establish three propositions, viz.:

1st. That railway traveling is dangerous.
2d. That railway traveling is safe.
3d. That the danger is potential, and the safety actual; and that the one has been converted into the other by the operations of scientific thought, and by the applications of scientific skill.

1. The first proposition is self-evident, and scarcely needs proof. No one has stood upon a station platform when an express train has rushed madly by without feeling that there was but a rivet, a bolt, or a rod between life and death. A broken tyre or rail would hurl dozens into eternity; a disordered permanent way would maim hundreds; the mistaken motion of a handle, the failure of a signal, or the transmission of erroneous instructions, would spread terror throughout the land. There is no sensation so great as that of a dreadful railway acci-

dent. It affects every one. All are travelers by railway, and natural selfishness makes us read with horror and dismay of the death of *units* in a railway train, while we pursue our breakfast with comparative calmness during the recital of *hundreds* smothered to death in a colliery explosion, or sent to eternity in a watery grave.

2. But is not the fact that, though we have just read the harrowing accounts of a dreadful collision in the north, we instantly entrust our precious bodies in a railway carriage to the south, a proof that there is also safety in railway traveling? Have we not faith in our railway managers, and is not this faith evidence of safety? How many of those present have been in an accident? But, after all, ideas of safety are but relative. Compare accidents on railways with accidents in the old coaching days. Take the loss of life at sea, the accidents in the hunting field, in boating, in bathing, by lightning, etc., and compare them with those on railways.

In 1873, 17,246 persons met with violent deaths in England and Wales, which is an average of 750 per million, or 1 in 1,354. The causes of these deaths are thus analyzed:

TABLE I.—VIOLENT DEATHS IN ENGLAND AND WALES FOR THE YEAR 1873.

Cause of Death.	No.
Injuries in mines	990
Mechanical injuries (not on railways or in mines)	6070
Chemical injuries	2784
Asphyxia	5193
Violence (unclassified)	919
Railways	1290

(*See Tables II and III next column.*)

This, however, is not the death-roll from all causes on all railways of the United Kingdom during the year 1874. The total number of persons recorded at the Board of Trade as having been killed was 1,424. Of these, 211 were passengers, and, of the remainder, 788 were officers or servants of the railway companies, or of contractors, and 425 were trespassers, or suicides, or others who met with accidents at level crossings or from miscellaneous causes.

Some of these may be further analyzed as follows:

TABLE II.—ANALYSIS OF TABLE I.

Cause of Death.	No.
Mechanical Injuries.	
Fall from scaffold (ladder)	165
Fall from window	70
Fall downstairs	456
Fall in ships and boats	134
Fall from height	500
Fall in walking	93
Fall (not stated how)	530
Fall of heavy substances on	509
Horse or other animals	269
Horse conveyance	1250
Machinery	1132
Fight	5
Blow, &c.	124
Gunshot wounds	185
Chemical Injuries.	
Burns	1064
Scalds	701
Scalds (drinking hot water)	50
Lightning	21
Sunstroke	96
Exposure to cold	138
Asphyxia.	
Drowned	3232
Suffocated by food	94
Suffocated by bedclothes	611
Hanged, strangled and executed	581
Murder, manslaughter and suicide	228

Let us take accidents to railway passengers from causes within, and beyond, their own control:

TABLE III.—ACCIDENTS TO RAILWAY PASSENGERS, from Causes within and beyond their own Control.

Date.	Within own Control.	Beyond own Control.	Total.
1871	45	12	57
1872	127	24	151
1873	120	40	160
1874	125	86	211
Average	104	41	145

This is an average of forty-one persons killed annually from causes beyond their own control, and it shows, in fact, that the railway companies are in reality more mindful of the lives of their passengers than the passengers are of their own lives.

These latter accidents can be classified as follows:

TABLE IV.—ACCIDENTS TO RAILWAY PASSENGERS in 1874, from Causes within their own Control.

Cause of Accident.	No.
From falling between carriages and platforms	49
Getting out off or into trains in motion	22
Crossing the line at stations	33
Falling down stairs at stations	2
Falling out of carriages during traveling of trains	9
Other accidents	10
Total	125

1874 was, however, a very exceptional year, for no less than 71 passengers were killed in the three fearful accidents on the Great Western at Shipton, on the Great Eastern at Thorpe, and on the North British at Browness Junction. Taking the following periods, the proportion of passengers killed from causes beyond their own control to passenger journeys made was:

TABLE V.—PROPORTION OF PASSENGERS KILLED TO JOURNEYS MADE.

3 y'rs ending	1849,	1 in 4,782,188	j'rneys made.
4 "	1859,	1 " 8,708,411	"
4 "	1869,	1 "12,941,170	"
3 "	1873,	1 "20,089,660	"

Taking the average length of each journey at ten miles, one passenger is killed, from causes beyond his own control, for every 200,896,000 miles traveled. If a person traveled ten hours a day, at the rate of thirty miles an hour for each of the 365 days of the year, he would probably be killed in 1,885 years. Hence, in a relative sense, we may consider that railway traveling is safe.

3. How is this potentiality of danger converted into comparative actuality of safety? Freedom from accident depends upon the perfection of the road, of the rolling stock, of the signals, and, above all, of the men. But none of these elements are perfect. Accidents have been analyzed into—

TABLE VI.—PERCENTAGE ANALYSIS OF RAILWAY ACCIDENTS.

Defective	permanent way	18 per cent.
"	rolling stock	13 "
"	signals	28 "
"	human machinery	41 "

They have also been classified as follows:

1870.	1871.	1872.	1873.	1874.	Nature of Accident.
9	19	21	34	18	From engines or vehicles meeting with, or leaving the rails in consequence of obstructions, or from defects in connection with the permanent way or works.
10	22	17	23	13	From boiler explosions, failures of axles, wheels, tires, or from other defects in the rolling stock.
..	2	7	5	..	From trains entering stations at too great speed.
61	9	22	18	9	From collisions between engines and trains following one another on the same line of rails, excepting at junctions, stations, or sidings.
18	19	32	20	22	From collisions at junctions.
Included in the above 61	63	91	98	75	From collisions within fixed signals at stations or sidings, &c.
3	2	5	3	6	From collisions between trains, &c., meeting in opposite directions.
1	..	..	3	1	From collisions at level crossings of two railways.
14	12	34	36	17	From passenger trains being wrongly run or turned into sidings, or otherwise through facing points.
6	11	9	11	7	On inclines.
9	12	8	6	..	Miscellaneous.
131	171	246	247	168	

Zeal and anxiety, the necessary evils of a state of tension due to increasing traffic; want of punctuality; late arrivals of the public; and variable weather, become an absolute source of danger. Every accident is traceable to its cause.

Purely inexplicable accidents are unknown. Hence, though considerable improvements in the mode of working have been made—as are indicated in the continued progressive increase shown in the ratio of killed to journeys made in Table V—further improvements are certain. But all improvements bring their own evils, and the greatest of these is human fallibility. The body will tire, and the brain will get out of gear. Pure wilfulness, carelessness, or mischief, are extremely rare. Who does not make a mistake? In the year 1874, 4,400,000 letters out of 967,000,000, or one in 220, found their way to the Returned Letter Office. 89,540 undelivered letters contained valuables, and bank-notes, bills, etc., the value of which alone amounted to £565,000; 337 of these had no addresses; 61,000 postage stamps were found loose in the different post-offices, and 20,000 letters were posted without any address at all.

How then is the comparative safety of railway traveling produced? By taking advantage of the lessons taught by experience, and by applying the means suggested by scientific thought and inventive skill to remedy defects. Failure has thus led to improvement. Every accident has been a lesson learnt, and bitterly have those suffered who have not profited by such writings on the wall. The particulars evidenced by each accident have been carefully and systematically recorded in the reports of the inspecting officers of the Board of Trade, and thus by recording past experience, the materials are collected for carefully generalizing the laws of railway-working, and for establishing a true science of steam locomotion.

Telegraphy, or the art of conveying information by certain pre-concerted signals to the ear and to the eye, is the chief aid of the railway engineer. Thus, at every railway station, level crossing, or junction, signal-posts are erected, which convey to the approaching engine-driver by exposing discs, bars, or semaphore arms in different positions by day, or lamps displaying different colors by night, the fact that the line is clear for him to proceed, or obstructed so that he must stop. The favorite signal by day—the survival of the fittest—is the arm, which, when at right angles, implies *danger*, and when at an angle of 45°, *safety*, and

> "White means right: red means wrong:
> Green means slowly go along,"

teaches the young railway lad the rule of the road by night. The character of every train is indicated by its *head-lights* and its presence to an approaching train by its *tail-lamps*. Should thick weather prevent the sight of the signals, detonating fog signals announce the contiguity of danger. The marshalling of trains in station yards and platforms is produced by whistles and flags by day and lamps by night, all forming a species of telegraphic language between the fixed station and the moving train.

Where telegraphy is required to reach distances beyond the sphere of the ear or the eye, electricity is employed, and the electric telegraph becomes of prime and essential use, not only in regulating the traffic on double and single lines, but in securing safety. Special trains are moved about by its means, delays are remedied, breaks-down rendered harmless, runaway engines have been overtaken by its aid, passengers' luggage recovered, but, above all, irregularities are by its means rapidly announced, and the evils of unpunctuality rendered innocuous.

The greatest element of safety on railways is, however, the Block System.

The block system arose out of the multiplication of trains, and the necessity for increased speed. Necessity the mother of invention, brought it into existence.

By it trains traveling upon the same line of rails are kept apart by a certain and invariable interval of *space*, instead of by an uncertain and variable interval of *time*.

The practice under the time system is to exhibit the danger signal for five minutes, and the caution signal for five minutes more, after a train or engine has been despatched from or past any station, junction, level crossing, or siding. Trains are thus said to be kept apart by fixed periods of five minutes, and if the caution signals were properly regarded, by an interval of time even longer than that. The safety of the train is entirely the responsibility of the driver. Immunity from accident is dependent upon his

keeping a clear look-out. If engines ran at regular and fixed speeds, if time tables could be adhered to, if the line were not crowded with traffic, if the driver could always ensure a good view before him, if signals were near together and they were properly regarded, then a rigid interval of time might be maintained between following trains; but none of these elements of safety are constant. Fast expresses follow slow goods trains, now through a thick fog, now up a wet incline, at one moment in bright sunshine, at the next in a thick snowstorm; creeping mineral trains break down in a long interval between two stations; passengers rush in at the very last minute, detain the train, and prevent the time tables from being adhered to; trains are so frequent at some places that the five minutes' interval cannot be adhered to; obstructions to view arise from curves or cuttings, or from atmospheric causes; long lengths of line are unprotected by any signal at all, and signals themselves are too frequently neglected. Hence, the system is brimful of elements of danger, and the inexorable logic of facts has shown that the time interval is illusory and the system unsafe.

But when trains, however rapidly or slowly they may be running, however much punctuality has been infringed, however crowded with traffic the line may be, are invariably kept apart by an interval of one or two miles, collision between them becomes impossible. This is the *Block System*, which has, very improperly, been divided into two classes, the *absolute*, and the *permissive*. The former is the block system proper, the latter is not a "block" system at all, but a system introduced, not to secure the safety of trains, but to increase the capacity of the line for the transmission of increasing traffic. It is, doubtless, an improvement on the time system, but it bears little affinity to the block, and should certainly not be included in the same category.

The block system is effectually carried out by means of electricity. Communication is maintained between station and station by means of bells rung by currents sent to announce the approach and departure of the trains. Permanent signals are raised and lowered, indices are moved to one position or another to indicate the presence or absence of danger, or the fact of the line being obstructed or clear. Indicators are moved to repeat back the signals made to check accuracy in working, and to render futile the errors or carelessness of the hasty or thoughtless. Safety is secured and accuracy in working is maintained by checks and by counterchecks.

The block system on single lines is additionally used to protect trains from *advancing* as well as from *succeeding* trains. Before a train is allowed to leave A the line at B is blocked in advance, and when it leaves it is blocked behind at A, so that it is thoroughly protected in both directions during the period it is running from A to B.

But apart from the protection which electricity imparts to railway traveling, and the facility it offers for adjusting and regulating the traffic, there are innumerable purposes for which the telegraph is employed to facilitate business and to secure efficiency. The distribution of correct time, the collection of spare trucks and coaches, the relief of staff, the supply of assistance in cases of accident and danger, and—not least—the reparation of the error and thoughtlessness of passengers.

It is used on some lines to establish an effective means of communication between passenger and guard; and perhaps one of its most useful applications is to record in the signal-box, before the signal-man's eyes, the position of the signal arm by day and the condition of light by night, which is hidden from his sight by the formation of the line, buildings, darkness, fog, or steam. Electric repeaters are of the greatest elements of safety in working railways.

The operation of scientific thought has introduced many mechanical elements of safety into railway working, which are as ingenious as they are effective.

Improved permanent way, the interlocking of signals and points; the concentration of levers in well-constructed cabins; effective break power; perfect tyre fastenings; better coupling arrangements, and superior engine and rolling stock, have all aided to secure that simplicity in working and safety in traveling which undoubtedly exist.

But, as the principal element of danger

in railway traveling consists in the fallibility of the human machine, it must not be forgotten that we owe our immunity from accident as much to the careful selection, education, and supervision of the staff and the maintenance of good discipline, as to the appliances of scientific skill. Science cannot be devoted to a nobler purpose than to the protection of human life, and the records of experience show that it has earned well-deserved laurels in rendering the dangers of railway traveling potential and its safety actual.

EXPERIMENTS WITH WATER METERS AT WIESBADEN.

By C. MUCHALL.

From "Journal für Gasbeleuchtung."

AFTER commenting on the great importance of water-meters for German towns, the Author points out the practical results from the trials of a large number of meters, in contradistinction to many experiments, lately published, with a single instrument of one particular system, which are almost useless, as they do not indicate how the meter acts in practice, to what accidents it is liable, and what is the cost of maintenance and repair, questions which can only be settled by long experience, but on which much of the accuracy depends. Although that meter is preferable which measures most accurately and the smallest quantities, no system of meters can ever come into general use in which the cost of fixing, maintenance, and repairs is large.

The four systems of water-meters used were those of Kennedy, Frost, Siemens, and Taylor, the two former being piston meters, and the two latter wheel meters.

The numbers of each on the 31st December, 1875, were as follows:

Calibre.	⅜ inch.	½ inch.	¾ inch.	1 inch.	1½ inch.	2 inch.	4 inch.	Total.
Kennedy	42	53	7	8	..	..	..	110
Frost..... ..	21	3	..	..	..	..	..	24
Siemens.....	11	258	886	36	5	3	1	1,200
Tylor	..	152	158	..	..	..	..	310
	74	466	1,051	44	5	3	1	1,644

The points to be taken into consideration were: 1. Degree of accuracy of the meter; 2. Duration of the initial accuracy; 3. Frequency of repairs; 4. Facility of fixing and removal; 5. Cost of purchase and maintenance.

Those of Kennedy and Frost were found to be most accurate; that of Tylor generally registered two to three pints per minute, while the Siemens meter would with a small flow either not register at all, or only very slightly.

Each meter was tried, before being used, with a Kennedy and a Frost meter known to be correct, and from time to time gauged by a measuring vessel of known contents. Both the entry and the outflow pipes were provided with cocks, that of the former being always wide open, to have the full pressure on the meter.

The outflow cock served to regulate the volume of water which flowed through. The trials were usually carried out by allowing 1,100 gallons to flow through in quantities varying from seven to thirty-five pints per minute. If the differences at the end of the trial were greater than ± 3 or 4 per cent., the meter in question was adjusted and tested as before. This adjustment only took place with the wheel meters, as the

piston meters always registered correctly when the piston was properly packed. The adjustment was effected either by slightly extending the blades of the fan, so as to make them travel more quickly, or by filing them down to diminish their speed, or else a counter stream was more or less increased, for which purpose the Tylor meter is provided with a set-screw, whereas the Siemens meter must be taken to pieces in order to be adjusted. It was found, however, that the latter adjustment was not accurate, as the influence of the counter stream on different volumes of water, passing through in the same time, was not the same.

The duration of the initial accuracy depends chiefly on the construction. The Frost and Kennedy meters registered accurately only so long as the piston packing and gearing were perfect. Kennedy meters were often found inaccurate on account of the india-rubber ring becoming concave. In this respect the wheel meters are to be preferred. It was found, especially of the Siemens meters which have been several years in use, that some show as much as twenty per cent. plus, and others a considerable minus. In both cases the variation may be attributed to rust, deposited either on the blades of the fan or on the axle. In the first instance this would increase both the surface of the fan-blade and its mass, and thereby have a tendency to increase its velocity, especially in the case of an irregular flow; whilst, if the rust is on the axle, the increased friction on the bearings would diminish the speed. It was also found that the same meter, after it had been cleaned from rust, registered less if the rust had been on the blades, but more if it was removed from the axle. Tylor meters, which did not exhibit similar inaccuracy, were also quite free from rust, so that meters whose casing consists of brass must be preferred to those of iron.

With regard to the frequency of repair, this is usually necessitated by their ceasing to work, but occasionally by leakages, illegibility of the dial, or damages. The latter causes are comparatively rare, and can never be totally avoided, but it is different when a meter stops working, which is essentially caused by a fault of construction. It appeared that Kennedy meters ceased to register when either the stuffing-box of the piston-rod or that of the valve-rod (steuerrungshahn) was tightened too much, or when the packing became hard and dry. With the heavy pressure, sometimes $8\frac{1}{2}$ atmospheres, this cannot always be avoided. It also failed when the india-rubber ring, which rolls up and down on the piston, got twisted or broken.

Of all the meters observed, those of Frost stuck most easily, as the complicated gearing, which is in the water, is soon covered with slime and ceases to work. As all stagnant water deposits slime, however slightly, the frequent stopping of this meter is a great evil, and it is rendered the more inconvenient because the meter, when fast, does not permit the water to pass.

In Siemens meters the cause of stoppage is usually slime and rust, either on the axle or on the wheel, or else deposited between the wheel and the casing.

With Tylor meters there have been several instances in which two or more of the fans have been broken off the wheel. This is partly caused by the brittleness of the metal of which they were made (since replaced by tougher metal), but more frequently by the presence of foreign substances, such as small pieces of lead or tin too fine for the meshes of the sieve, which caused the fan-wheel to jam, generally the result of careless soldering and repair; these may be kept back by the sieve for a long time, and though not bigger than the head of a small pin, may at length suffice to stop the meter.

Of the sixteen hundred and forty-four meters fixed up to the end of 1875, one hundred and ninety-five stuck in the course of that year. They were—

(*See Table on following page.*)

All these had to be taken out excepting the majority of the Kennedy meters, in which the gearing had become clogged. If in the two latter, allowance be made for stoppages caused by tin between valve and case, as not properly depending on the construction of the meter, there remain six per cent. of stoppages with Siemens meters, and none with Tylor.

Besides these stoppages, and the repairs rendered necessary by them, one hundred and thirty-five meters, or about

	Total Meters.	Total Stopped.	Per-centage.	Cause of Stoppage.			
				Broken piston-ring	Gearing clogged.	Rust in Meter.	Tin betw'n Fan & Case
Kennedy	110	50	45	10=9%	40=36%	..	..
Frost	24	2	8	..	2=8%	..	..
Siemens	1,200	128	11	..	..	68=6%	60=5%
Tylor	310	16	5	..	..	..	16=5%
	1,644	196	..	10	42	68	76

eight per cent., required slight repairs, such as leakages in the stuffing-boxes, replacing dials, glasses, padlocks, &c., in which the meter rarely required to be changed. To complete the list it must be added that thirty were damaged by frost.

In respect of facility of repair and removal the Kennedy meter is the least handy from its size and weight. The others only need one workman to fix them, but the Kennedy and the largest size of the Frost meters require two. Tylor and Siemens meters are in this respect nearly equal, but the Tylor meters are somewhat cheaper to fix than those of Siemens, as no soldering is required.

The piston meters are so much more expensive than the others, that on this ground alone they are never likely to come into general use. For example, a $\frac{3}{4}$-inch piston meter by Kennedy cost about three times as much as a $\frac{3}{4}$-inch Siemens or Tylor meter, and a $\frac{1}{2}$-inch costs twice as much. This proportion should not form the basis of a comparison, as through meters of equal diameters, but of different systems, the maximum flow is not equal, the proportion of water passing through the $\frac{3}{4}$-inch and $\frac{1}{2}$-inch meters of Kennedy, Tylor, Siemens, being about 100: 65: 60.

With a pressure of 75 meters (240 feet) the maximum flow would be as follows:

System.	1 inch.	$\frac{3}{4}$ inch.	$\frac{1}{2}$ inch.
	Maximum flow in gallons per minute.		
Kennedy	70.2	37.2	22.0
Tylor	..	24.1	14.1
Siemens	48.2	23.0	1.31

These results are too small for Kennedy meters, for as the resistance in the pipes increases with the velocity, it is incorrect to take the calibre given by the manufacturer as the standard of comparison. Both with regard to cost and to calibre for pipes of a certain size, only meters of equal performance can be compared. Moreover, with a normal consumption, the gain in accuracy is not so great as to render a considerable addition to the cost advisable, for with thousands of meters any slight errors in some would probably be balanced in others.

As to the cost of maintenance, the above percentages cannot fairly be compared, as the meters of Kennedy and Siemens have had the most wear; but there can be little doubt that the cost of maintenance with the Kennedy meter is by far the greatest, and that Siemens meters do not seem to be so favorable as those of Tylor. As the latter is made of brass, stoppages caused by rust are not to be dreaded, whilst as the former consists almost entirely of iron, this cause of stoppage will continue until the iron be changed for brass. Rust brought in from the cast-iron street pipes is of no importance, as with well-tarred pipes the formation of rust is very slow. But even if any finely-divided rust does pass through, the best proof that it does not injure the meter is that none has ever yet been found in the Tylor meters. It is probable that the union of iron and brass under water favors the formation of rust in the Siemens meters.

With regard to damage by frost, in the Kennedy meters the cylinder always bursts; in those of Siemens part of the casing also gave way, and the indicator was pressed out of place; whilst in the Tylor meters no part had burst, the indicator only had been pressed out of place, and the soldering of the casing had come

undone, so that the repairs to the latter cost less than those to the other two systems.

On comparing the results obtained from the four systems, the piston meters were not recommended for use in private houses, for, constructed as they are at present, the advantage of greater exactitude in measuring is more than counteracted by the increased cost of purchase and maintenance.

For house purposes the wheel meters of Siemens, or still better, those of Tylor, are more serviceable.

THE STRENGTH AND DIMENSIONS OF SPRINGS.

From "The Engineer."

THE frequency with which we receive requests for information upon or reference to some work in which information may be found upon the strength, deflection, &c., of springs as used in railway carriages, wagons, and other vehicles, either as bearing or draw springs, is sufficient proof that that information is not easily to be found, and that no apology is needed for here reverting to the subject. Probably no piece of mechanism of universal use has received so little attention from writers of text-books on mechanical subjects as a carriage or wagon spring of the ordinary and most generally used form; yet it is an interesting and important subject, and a somewhat complex one taken in all its bearings, and one which has afforded a useful opportunity for the exercise of the talent of some of our mathematicians and physicists, but only a few of whom, however, have reduced the results of their labors to a form available for the use of engineers and constructors who desire properly to proportion the parts of springs they may be called upon to design for locomotives, carriages, road wagons, and other purposes. Not that sufficient information does not exist of a practical kind to enable those engaged in the design of springs to arrive at correctness in the proportion of their parts to suit given conditions, but that which does exist in a suitable form for the ready application of the practical engineer is scattered amongst the transactions or proceedings of learned and technical societies, or only to be found in the more expensive volumes not easily accessible to every one who may require the information. We propose, therefore, for the convenience of those of our readers who may require, but find such information difficult of access, to give here a short practical view of the subject, and, as far as our space will allow, to give such formulæ as are most generally applicable in the design of that kind of spring, namely, the plate spring, which practice proves to be the best for both bearing and draw springs. It is not our intention to dwell upon the curvature assumed by elastic bodies, nor upon the investigations upon which the formulæ we are about to quote are based, as this would be beyond the purposes of this article, and would unnecessarily complicate and lengthen it.

The value of a spring may be said to consist in its range of elastic flexure, and in its giving an uniform range of deflection under any one load between the minimum and maximum weight it is calculated to carry, and in its capability of overcoming the inertia of vertical motion of the load it is carrying within its assigned range of deflection; and, conversely, in its capability of permitting the vertical movement of the wheels and axle of the vehicle without immediately imparting that motion to the load, and thereby relieving the wheels and axle of the shock attending the work of suddenly overcoming the inertia of rest of the load, these properties coming into play respectively according as the load is suddenly checked in descent, when the wheels drop from a projection to the general surface of the roadway, or as the wheels are as suddenly raised by such a projection. In a vehicle not fitted with springs the whole weight of load and vehicle has to be raised through the height of every obstacle in its path on an irregular road, and if the vehicle be

traveling at only four feet or five feet per second, the raising of the whole is effected so suddenly that the work of overcoming its inertia and lifting it, seriously tries the material of the wheels and axle, and adds very materially to the work of pulling the load. If, however, the vehicle be fitted with springs the work of suddenly lifting the whole load and vehicle is reduced to that of lifting the wheels and axle and deflecting the springs through a certain range, the latter being only equal to that of raising the weight necessary to produce such an increase of deflection. This work is absorbed by the springs, and is, in some cases, partially given out as useful work —as, for instance, when the obstruction is only momentary, as in passing over a fixed stone—in the descent of the wheels through the miniature gradient on the opposite side of the obstruction. This latter also obtains with the springless vehicle, as far as regards the descent of the weight and the slight forward impetus thus given to it, but the work of overcoming the inertia of the load is wholly lost.

Thus, with the springless vehicle the work added to that of traction in surmounting any obstacle may be taken as equal to that of overcoming the inertia of the load and lifting it, while, in the case of a vehicle fitted with springs, it is only equal to that of momentarily carrying an addition of load equal to that necessary to deflect the springs through the height to which, in the other case, the whole load has to be lifted. To meet these conditions, therefore, it is necessary that springs should, if possible, be uniformly flexible throughout their length, and should deflect through sensibly equal ranges for equal increments of load, so long as the load is within the limits of their capacity. Inasmuch, however, as the span of a spring slightly increases if normally curved, and decreases if normally straight, with every addition of load, the deflection becomes respectively more or less with each similar increment of load; no plate spring can, therefore, be equally efficient under greatly varying weights; hence it is of great importance, especially in railway vehicles, that the difference between the minimum and maximum loads should not be great, and that it should be accurately known and taken into consideration in the design of the springs.

The elastic strength of a spring is measurable by the load necessary to produce a given deflection within the limits of resilience of its integral parts; and on the other hand, its flexibility is measured by the range of deflection produced by a given load; while the strength of a spring is expressed by the load it will carry without approaching fracture or the limits of stability of its material. When a spring the plates of which are properly tempered is loaded beyond its elastic strength, it deflects through an abnormal range which generally indicates approaching rupture, or, if not actual rupture, such deformation as precludes its return to its original form, the strain on its material having exceeded its limit of elastic resistance; and this great increase of flexure must not be mistaken for increased elasticity. The absolute strength of a spring is thus not co-equal with its elastic strength, and the relations of the terms expressing the relative dimensions and properties as to strength and flexibility of plate springs may be thus summed up.

The absolute strength varies inversely as the span, directly as the number and breadth of the plates, and as the square of their thickness; while the flexibility varies as the cube of the span, inversely as the number and breadth of the plates, and inversely as the cube of their thickness. Thus the flexibility increases in a much higher ratio than that expressing reduction of strength with increase of span. These relations will be seen at a glance expressed in an algebraical form as follows, some of the formulæ being quoted from Mr. D. K. Clark's work on "Railway Machinery :"—

Let D = the deflection in sixteenths of an inch per ton load.

S = the span of the spring in inches when loaded.

b = the breadth of the spring plate in inches, considered uniform.

t = the thickness of plates in sixteenths of an inch.

n = the number of plates.

W = the working strength of spring in tons, or safe load.

Then

$$W=\frac{n\,b\,t^2}{11.3\,S}$$

$$D=\frac{1.66\,S^2}{n\,b\,t^2}$$

$$n=\frac{11.3\,S\,W}{b\,t^2}$$ and n necessary to a given elastic flexure, span, and size of plates=

$$n,=\frac{S^2\,1.66}{D\,b\,t^2}\,*$$

Plate springs, in almost all their applications, are liable to have their load suddenly applied, in which case the deflection will be, approximately, twice greater than when the load is gradually applied, or has been carried a short time, or sufficient time to allow of the spring adapting itself to the load after a series of oscillations. In other cases the load, or increment of load, is so suddenly applied as to become an impact force, in which case, supposing the spring to be without weight, and therefore without inertia, the deflection will be as if produced by a falling weight, and will be given by the formula

$$D=\sqrt{\frac{2\,w\,H}{\tau}+\left(\frac{w}{\tau}\right)^2}+\frac{w}{\tau};$$

in which D=deflection in feet, τ the static pressure in pounds which will produce a deflection of one foot, w the weight in pounds of the falling body, and H the height in feet through which it falls. In the case of bearing springs, H may be obtained by the formula, $H=\frac{v^2}{64}$, v being the velocity of impact force, or of the jerk which the spring has to resist, and, supposing for this purpose that the pressure required to produce one foot deflection is proportional to that required to produce deflection through small ranges—

$$\tau=\frac{n\,b\,t^3}{S^2}\times 259{,}000$$

This increase of deflection under sudden application of load must be borne in mind in arriving at a decision as to the range of deflection, and in designing the parts supporting and guiding the springs, and to prevent a spring getting away from its work by reason of its high velocity of recoil when the wheels suddenly drop from a higher to a lower elevation, it should be deflected through a considerable range by its permanent load, the amount of such deflection varying with the nature and use of the spring, and being for passenger carriages, goods, vans, &c., from $\frac{3}{4}$ inch to 1 inch.

The thickness of spring plates must be regulated by the span. A long spring may have thick plates, but a short spring with the same flexure must have thin plates, the thickness being so proportioned to the span and deflection that the extension and compression of the upper and lower surfaces of the plates are not sufficient to reach the limits of elasticity of the steel. Some years since thick plate springs were tried on the Great Western and other railways; but experience proved—what theory properly applied would have predicted—that thin plates were, for many reasons, superior, though we have heard it professionally stated within the past few months that it was not known why such was the case. Inasmuch as flexure cannot be obtained without extension or compression, or both, of the opposite sides of the plate bent, infinite flexure could only obtain with infinite thinness of plate; and as the possible elastic extension or compression of the material of which the plate is composed is limited to a small range, it is patent that there exists a quickly reached superior limit to the thickness of a plate of a given length which is to be deflected through a given range, and that if this limit is exceeded, deflection through the same range will be attended with permanent set or by fracture. Thus, with a given thickness and length of plate the range of elastic flexure is determined by the limit of elasticity of its material, and therefore the maximum economic thickness is similarly determined by the range of flexure and the limit of elasticity. The superior limit being thus found, the inferior limit will be determined by the assigned range of deflection, and by constructive limits as to number of plates or total depth of spring at center. It has been found by experience that for springs under 3½ feet to four feet in span, the thickness of the plates should not exceed from ¼ inch in the smaller and

* The constants 1.66 and 11.3 were determined by Mr. Clark from the observed deflection and strength of springs of which he gives an account.

$\frac{5}{16}$ inch to $\frac{3}{8}$ inch in the larger spans while for springs above $3\frac{1}{2}$ feet and up to five feet and six feet span plates are now rarely used of more than $\frac{1}{4}$ inch in thickness with, in the larger spans, one or two $\frac{3}{8}$ inch top plates. Except for light carriages and similar vehicles the two, and in heavy vehicles and locomotives three, upper plates should be of nearly the same length, and the upper one of slightly increased thickness, the length of the lower plates decreasing by such steps that the spring may as nearly as possible deflect equally at every part throughout its length, except a few inches at the central fixed part or butt. The amount of deflection varies with the different applications of springs. In locomotive engines the flexure for the driving and trailing wheel springs ranges between $\frac{3}{4}$ inch and one inch and for the leading wheels not more than $\frac{1}{2}$ inch per ton of load, or even less, more especially when the springs are placed within the wheels. Passenger carriage springs varying in length from four feet to six feet, deflect from $1\frac{3}{4}$ inch to $2\frac{1}{2}$ inch per ton of load, while the common deflection of horse-box springs is from $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch per ton. For goods wagons a deflection per ton of load of from $\frac{5}{8}$ inch to $\frac{3}{4}$ inch is sufficient. Springs have been made with pieces of plate iron about $\frac{1}{8}$ inch thick placed between each spring plate at the butt, thus keeping the spring plate apart for some distance from the center. This, however, does not seem to be good practice; the paint on the surfaces thus exposed in the space between each plate is rubbed off during the working of the engine by the contact of the plates to a distance much nearer the center than when the engine is standing still or running at moderate speeds, and these interstices become seats of corrosion and wear. The plates cannot be "bedded" on each other too well, and paint is of little use between the rubbing surfaces; it is quickly rubbed off and out from between the plates, except at such inequalities as may exist whereat the plates do not quite touch, and here it may be of some service in keeping out water from such cavities; but the spring whose plates are best fitted together will last the longest.

ON THE CONSTRUCTION OF RAILWAY WAGONS, WITH SPECIAL REFERENCE TO ECONOMY IN DEAD WEIGHT.

By WALTER RALEIGH BROWNE, M.A., Assoc. Inst. C.E.

Minutes of the Proceedings of the Institution of Civil Engineers.

The present paper is mainly an essay towards determining the best and lightest form of goods wagon for general purposes to run on an ordinary English railway. It is, of course, a chief condition in such a wagon, that it shall enter readily into combination with the stock at present in use. The Author has therefore left unnoticed many points which it would be proper to discuss were the question that of designing the best type of vehicle for a new and independent system of railways. As an example, may be mentioned the various systems of central buffer and draw couplings which have lately come into extensive use on new foreign lines, especially those of a narrow guage. Whether these, in their own place, are beneficial or not, there can be no question that any vehicle intended for English main lines must have side buffers, placed at the same height from the rails, and the same distance apart, as those with which it will everywhere come in contact. For a like reason, while attention has been given to the practice of the best railways on the Continent and in America, this has only been considered as illustrating and throwing light upon the various characteristics of the English system. It was originally intended to include the subject of carriages as well as wagons; but this proved at once so large and so distinct, that, with the limits of time and space allowed, it was impossible to discuss it properly. Although alike in their principal parts, a carriage and a

wagon differ widely in their essential conditions: not merely must a carriage be adapted to a much higher speed than a wagon, but considerations of smoothness, comfort, and luxury, wholly wanting in the latter, are of paramount importance in the former. Hence, although considerable information had been collected on the subject of carriages, it was thought better to reserve this for some future occasion.

The designing of a railway wagon has its peculiar difficulties, arising from the fact that, in addition to the ordinary strains, which can be calculated and allowed for, such a wagon is also subject to sudden and extraordinary strains which defy calculation. The violent shocks and strains of all kinds which a wagon is continually called on to endure need no description to any one who has ever watched the handling of goods traffic on railways. It is these which have chiefly to be considered in the building of a wagon. Extreme cases, such as a collision, or what Americans call a "derailment," cannot, of course, be guarded against; but the leading principle must be that all parts should be strong enough to sustain, without injury, the greatest shocks to which they are liable in ordinary working. It has not, therefore, been attempted to give a complete theoretical investigation of the strains on a wagon, or to frame a design and dimensions on theoretical principles. The dimensions found in the practice of the leading English railways have in general been assumed as substantially correct. What has been aimed at is to compare these with each other (checking them also by theory wherever possible), and thus endeavor to arrive at the lightest and most economical design consistent with the practical conditions of the case. These lead at once to the principle just stated, viz., that the strength of a railway vehicle must not, as in other structures, be proportioned to the load it has to carry. To show this by an example, take the ordinary sole-bar of an eight ton or a ten ton wagon. This, following the dimensions specified by most railway companies, will be a piece of American oak, twelve inches deep by five inches wide, and carrying a distributed load over a length of about fourteen feet. Taking ten tons as the load, and four tons as the weight of the wagon itself (exclusive of wheels, axles, and springs), this distributed load will be seven tons, or just one-half ton per foot. This load is supported on the two axles, which may be taken at eight feet apart. On calculating the bending moments at the center of this wheel base and over the axle respectively, it will be found that the latter is the greatest, and that its value in inch-tons is $\frac{3}{2} \times 18$, or 27. But calculating the breaking strain of a twelve-inch by five-inch section in the ordinary way, and assuming 4.7 as the modulus for inch-tons, the moment of rupture is found to be 564. This gives a factor of safety of twenty-one, or at least double what would be required in an ordinary timber structure. It follows that some other consideration must have led to the fixing of this scantling; and this of course lies in the fact, that the sole-bar has not merely to carry the load, but to carry it under all the varying circumstances of shock and strain which have already been alluded to.

It might seem an obvious deduction from the foregoing that the load of wagons (meaning thereby the total weight carried, in opposition to the 'tare,' or dead weight) ought to be largely increased. If the underframe of a wagon must in any case be made so strong that it would carry twenty tons as easily as ten tons, would it not be true policy to put something approaching to twenty tons upon it? This leads at once to the question, which ought obviously to form the first stage of inquiry, viz.: What is the proper load for an ordinary wagon?

Since, as already stated, the dimensions, and therefore the weight, of a wagon framework are, for the most part, fixed by considerations other than the weight it has to carry, the leading principle in this inquiry would seem to be that the load should be as great as possible. The way in which this principle has worked is shown by a glance at the history of railway rolling stock. The wagons first built carried only three or four tons, and weighed as much or more. From this the load was gradually increased to six tons, and then to eight tons and ten tons, at which it has stopped, although still the wagon is too strong for its load. Between these last

two sizes the question may be said practically to lie. It is true there are still many six-ton wagons running, but few are now built, at any rate by railway companies themselves; in fact, the weight and cost of a six-ton is not much below that of a ten-ton wagon, while the load is little more than one-half. The question being thus narrowed, the difference between the weight and cost of an eight-ton and a ten-ton wagon has to be considered. It must be admitted that this is not great. An ordinary eight-ton wagon, as built by the Bridgwater Engineering Company, to run on the lines of the Great Western Railway Company, and to pass their inspection. The under-frame is entirely of oak, the sole-bars-headstocks, and middle bearers being all twelve inches by five inches, and the diagonals eleven inches by three inches. The wheels are three feet in diameter, with eight pairs of wrought iron spokes, and weldless iron or Bessemer steel tires, five inches by two inches, secured to the skeleton by rivets. The axles are five inches diameter within the boss, and 4½ inches diameter at the center, the journals are 7 inches by 3½ inches. The bearing springs are three feet three inches long by three inches wide, and consist of twelve plates each ⅜ inch thick, and one plate ½ inch thick. A similar wagon to carry ten tons differs from the above only in a few particulars. It is longer and deeper, the length being thirteen feet seven inches, and the depth three feet six inches. The underframe is the same, except as to the longitudinals. In the eight-ton these only run between the middle bearers, and are eleven inches by three inches: in the ten-ton they are one inch wider. In the end spaces the eight-ton has only two light pieces, 4 inches by 3½ inches, above and below the drawbar; whereas the ten-ton has an eleven inch by three inch longitudinal running on either side the drawbar. It has also 1¼-inch longitudinal tie-rods in place of ⅞-inch tie-rods in the eight-ton. The wheels are the same, but the axles are 5½ inches inside the boss and 4½ inches at the center, the journals being 8 inches by 3¾ inches. The bearing springs are of the same length and design, but are four inches wide instead of three inches. The ironwork is the same throughout. The weight and cost of these extras are not great; in fact, while the tare of the eight-ton wagon is about four tons seven cwt. that of the ten-ton will not be above four tons fourteen cwt.; and, taking the price of the former at £60, that of the latter will not rule above £64. This comparison would appear to prove that the ten-ton wagon was decidedly the proper type, and that, as even here the factor of safety is far too high, a yet greater load might be resorted to. This conclusion, however, is negatived by the two following considerations:

(A) Wagons have not only to be hauled by locomotives; they have also to be shifted by horse power in yards and sidings: obviously, therefore, it is a fatal objection if a wagon is too heavy for a single horse to move it. Now it requires all the strength of a powerful horse to start a ten-ton wagon, fully loaded and in ordinary working order, upon a dead level: to start it on anything like an incline is too much for him: hence ten tons is, at any rate, the extreme limit admissible for the load.

(B) It is comparatively seldom that a wagon is loaded up to its full capacity. This arises from several causes. Thus (1) The contents of a wagon are often too bulky to make up the full weight. (2) The whole quantity of goods to be sent is often less than this weight: a truck comes into some private yard and is loaded, say, with three tons of castings, which are quite sufficient to constitute what is called a "truck-load": it is returned to the station, and thence goes direct to its destination, no weight being added, because nothing else offered having the same consignment. (3) The goods traffic on a railway is seldom equal in the two directions: hence wagons have constantly to be sent back empty. There are, unfortunately, no statistics with respect to English railways which will enable a judgment to be formed of the effect of these causes, and so to approximate to the average load of a wagon. For the railways of France, however, such statistics do exist, though not in a perfect form. These have been ably analyzed and discussed by M. Ernest Marche. Taking the six great railway systems of France, he finds that the ratio of the mean load to the capacity (or greatest load) of a wagon varies from 0.37 on the Chemin de Fer de l'Est

to 0.444 on the Chemin de Fer du Nord: the average being exactly 0.4. On three of these railways the effect of the return of empty wagons can be separately estimated, as the number of these empties is registered: the percentage of these in the three cases was 25.35, 20.46, and 14.89 respectively. Eliminating this effect, the mean load of the wagons actually freighted can be ascertained: in these three railways its proportion to the capacity was 0.495, 0.472, and 0.473 respectively. The sum of his results amounts roughly to this: that on the railways of France one wagon in five is running empty and the other four are loaded to rather less than half their carrying capacity. For English lines, as already stated, no such data are available. It is possible that, from their much larger mineral traffic, they would show more favorable results: but the difference probably would not be great. Looking at these figures, and remembering that the extra weight and cost of a ten-ton wagon are entirely wasted whenever its load does not exceed eight tons, it would seem that the latter is probably the best figure to take for purposes of general traffic. An exception may arise in the case of coal or ore wagons owned by private firms and used only for a single purpose. These are commonly loaded at the pits to their full weight, and in such cases the shunting is so generally done by engine instead of by horse power that the other evil is not so important. Taking, however, an ordinary goods wagon, such as railway companies use for general purposes, the case may be summed up by saying that even if built for ten tons it will rarely have more than eight tons to carry, and that when it has, its cumbrous weight will be likely to cause trouble both at the beginning and at the end of its journey.

For these reasons in what follows eight tons will be taken as the standard capacity; and an investigation will be made of the best design for an eight-ton wagon, in all its parts. The conclusions arrived at will apply, with little variation, to a ten-ton wagon.

Before entering on this, however, there is one other point which it is necessary to discuss. This is the question, whether it is wise to provide as far as possible special types of wagon for the various classes of traffic. This proposal has often been made, and is certainly plausible at first sight. As it has been put to the Author, a heavy wagon may receive, say at High Wycombe, a consignment of cane-bottomed chairs, to be delivered at Bristol; and though built for ten tons, will be thus traveling with a load amounting only to a few hundred-weights. Or again, the Great Western railway forwards daily throughout the spring many trucks full of cauliflowers, grown in Cornwall, but destined for the London market. In these and all similar cases there is no doubt that special types of light wagons might be designed which would offer great advantages for the conveyance of these particular loads. But this course is open to two fatal objections.

(1) Suppose the light wagon to have deposited its freight of chairs at Bristol. It has then to be sent back, and it is of course desirable that it should not go empty. But the goods going from Bristol towards London are not of a light character, and perhaps the only consignment offering is a ponderous casting, or some heavy barrels of sugar. There is then only the choice between sending the wagon back light, or loading it beyond its proper capacity.

(2) Whether loaded or not, the light wagon will have to travel as one of a long train of wagons, most or perhaps all of which are of a much heavier and stronger build than itself. In cases of accident, or in the ordinary events of shunting, starting, and stopping, the light wagon will be much in the position of the earthenware pot in the fable: it will meet with so much rough usage, will be so mauled and hammered by its neighbors, that its life, under the most favorable circumstances, will be of short duration.

These two considerations seem fully to justify the course which has been taken by railway companies, both here and on the Continent, in reducing as far as possible the number of classes of wagons. There must always, however, remain a considerable number of varieties to provide for traffic to which ordinary wagons are unsuitable. The chief of these, as at present existing, are cattle wagons, timber wagons, coke wagons, platform wagons for heavy

masses, such as boilers; covered wagons for perishable goods, etc. But much may be done to economise even these: thus cattle wagons may be used for coke, or at another time for light bulky articles, such as would generally be carried in covered wagons; boilers may be conveyed on timber wagons, and so forth. Far from agreeing with those who would wish to see classes of wagons multiplied, the Author's view is exactly the opposite. The end which should, in his opinion, be aimed at, is to have all ordinary wagons, not only on one railway, but throughout the kingdom, of precisely the same type and dimensions; this type being that which study and experience finally decide upon as the best. To help towards such a decision is, in fact, the principal object of the present Paper. Many advantages would result from this uniformity in wagons, which would of course extend to all their parts. A wagon, no matter what district it was built for, would always be free to work in any part of the country; whereas now it continually happens that a wagon is admitted without question by one railway company, which would be refused registration by another, as not complying with some special regulation. The wagons of the Taff Vale railway, for instance, are essentially different from those of all other companies, and would not be accepted by them: while a wagon that would be free over the whole vast system of the Great Western, would not be admitted on the Taff Vale. Again, any proposed improvement in design would of course have to go before a committee of wagon superintendents, and would thus at once be more easily brought to notice, and more thoroughly tested before approval. But the chief advantage would lie in the facility of repairs. All working parts being uniform, there would be no difficulty in keeping a stock at every repairing station, which would thus suit every wagon that could possibly arrive; and the cost of effecting every sort of repair would be accurately known, and could be charged according to a fixed schedule. On this system railway companies might with great advantage undertake the whole repairs of wagons in their district, and thus do away with the present system of repairing contracts, with which they profess themselves dissatisfied. The matter would be as simple as possible. On a wagon being stopped at a station, the foreman in charge would notify to the owner the repair required, and proceed to execute it. There could be no question as to the charge, and the amount of this might be collected, if advisable, before the wagon was allowed to proceed on its journey. This would do away with all the objections now felt to freighters' wagons, as it would insure that they were kept up to the same standard of efficiency as those belonging to the railway companies themselves. This would be an advantage also to the freighters themselves, and they would also reap the benefit of getting all breakages repaired without an instant's delay; whereas a wagon is now frequently kept idle for days or weeks, while an axle-box or buffer-case of a special pattern is obtained from the only place, perhaps hundreds of miles distant, at which it can be manufactured.

Having, then, decided that the load of the standard wagon is to be eight tons, and that it is to be of a form as generally useful as possible, the next consideration is its design in detail.

For this purpose a wagon may be divided into the following parts, beginning from below:

A. Wheels and axles.
B. Axle-boxes.
C. Springs.
D. Underframe, axle-guards, &c.
E. Draw-gear.
F. Buffers,
G. Body.

A. *Wheels and Axles.*—The type of wheels and axles commonly employed for ordinary freighters' wagons in this country consists of a cast-iron nave or boss, wrought-iron spokes cast into it, and bent round to form a skeleton on which a steel or weldless-iron tire is shrunk and secured by rivets.

The diameter of the axle is five inches in the wheel seat, and $5\frac{1}{2}$ inches just inside the wheel, thus forming a shoulder; thence it tapers to $4\frac{1}{4}$ inches in the center; while outside the wheel it is reduced to $3\frac{1}{2}$ inches for the journal, which is seven inches long. These dimensions do not vary much from those in use on the chief systems both at home and abroad. Thus the Great Northern Rail-

way Company specify five inches in the wheel seat, but reduce to four inches in the center, and $3\frac{1}{4}$ inches in the journal. The London and North-Western railway agree with these, but are content with $4\frac{3}{4}$ inches in the wheel seat. The Paris and Mediterranean give five inches in the wheel seat, $5\frac{1}{16}$ inches at the shoulder, $4\frac{1}{2}$ inches at the center, and $3\frac{3}{8}$ inches in the journal. The Cambrian railway and the chief German railways, however, are content with $4\frac{1}{2}$ inches for the diameter in the wheel seat; and the Grand Trunk of Canada specify $4\frac{1}{4}$ inches only, tapering to four inches in the middle.

The great diminution in size, both at the journal and in the centre, is, at first sight, hard to account for. The axle may of course be considered as a beam, loaded at each end (in the journals) by the half weight of the truck, and kept in equilibrium by the two upward pressures of the rails, passing through the wheels. It thus is under the action of two equal and opposite couples, in which the force is half the weight of the truck, and the arm is the distance between the centre of the journal and the centre of the boss. As the effect of such a couple is precisely the same at every point of the axle, it would seem that the diameter should also be the same everywhere. But it must be obvious that an axle is never endangered by the regular statical load brought upon it: its fracture is always occasioned by some sudden shock, such as might be caused by a stone placed on one of the rails, when the whole axle will act, for the moment, as a beam fixed at one end and receiving a blow at the other. This will of course produce its greatest effect at the fixed end, *i.e.*, in this case close to the undisturbed wheel; from thence the effect will diminish to its lowest value at the other, or disturbed wheel. This is the reason of the reduced diameter at the centre, the strain there being always less than at one or other of the wheels. The diminution is of course proportional to the moment of resistance, and therefore to the moment of inertia of the section: as this in a circle varies as the fourth power of the radius, the ratio of the diameter at the centre to that at wheel seat should equal $\sqrt[4]{\frac{1}{2}}$, or 0.84, a proportion very near to that found in practice.

The utility of this diminution has been questioned by M. Couche; but the above reasoning seems fully to demonstrate its theoretical soundness, while practically it effects a considerable saving in weight and cost.

The same reasoning, of course, accounts for the well-known fact that axles generally break just inside the wheel seat. This point is, in fact, that at which the cantilever is fixed (considering the axle as such), and therefore at which the intensity of strain is greatest. It is therefore desirable to avoid anything which may tend to weaken the section at this point. On some railways it is the practice to have a shoulder about $\frac{1}{8}$ inch deep on the axle, just inside the wheel, to prevent the latter from working inwards. The great tightness, with which wheels are now fastened to their axles, seems to render this unnecessary, and, in fact, on many lines it is dispensed with altogether. In any case, the difference between the first and the finishing cut of the lathe used in turning down the axle would seem to be amply sufficient. Anything more than this is objectionable, from the well-known fact that an abrupt change of section, in any piece subjected to impulsive strains, has a marked tendency to produce fracture. This, which has long been recognized and acted on in the case of shoulders, is probably also the reason why keys have frequently been condemned as means for fastening on wheels. But this would seem erroneous; for, in the case of a keyway, the shoulder runs parallel, and not at right angles to the direction of strain, and can therefore have no actual tendency to produce fracture. A keyway must of course be to some extent a source of weakness by diminishing the diameter; and to this is probably due the fact, observed by French engineers, that the fracture of an axle usually begins at the point diametrically opposite to the keyway. It is now becoming the practice to dispense with keys altogether, and simply to use so powerful a pressure in forcing the wheel on to its axle, that the adhesion so produced is sufficient to keep the wheel tight under all possible strains. It may, however, be questioned whether this is not itself dangerous in another way. The wheel being thus, as it were, incorporated with the axle, the latter is

somewhat in the position of a piece whose section alters suddenly and to a large extent. The evil of this is well known, and has been already alluded to. At the same time the boss is put into a state of violent strain (at least in its inner portion), and it is thus liable to split when any shock comes upon it. The splitting of bosses is, in fact, of frequent occurrence.

Looking at these considerations, there seems great want of a method for uniting these wheels and axles which should be sufficiently firm, without throwing either into a state of internal strain. An obvious method would be to make the wheel seat oval or hexagonal, instead of round; but this would, no doubt, add to the expense of machining. Perhaps the single key as now used, with some simple arrangement to prevent the possibility of its working loose, is as good a system as exists at present; at any rate, until some better be devised, four and a half inches at the wheel seat, tapering to four inches in the middle, would seem to be the smallest diameter permissible for an axle.

The greatly diminished size which may be given to the journal is due to the fact previously noticed, viz., that it is a blow delivered by one rail which produces the most violent strain on an axle. Another cause, however, no doubt comes in to assist the journal, and that is the operation of the bearing spring, through which the weight is transmitted. When a wheel passes over an inequality, the weight of the truck must of course come heavily down upon the journal; but the effect is taken off by the yielding of the bearing spring, and changed from a violent blow into a graduul pressure. This leads to the inquiry whether the shock to the wheel seat might not be, to some extent, "cushioned" in a similar manner. This clearly implies the giving of a certain amount of elasticity to the wheel itself; and this has apparently been accomplished in the wooden wheel system, now so frequently used, especially for carriages. The space between the boss and the tire is here filled up by a series of hardwood blocks, set endwise to the fibers, and secured both at the boss and the tire by rings of plate iron. This system has been in use on the London and South-Western railway for thirty years. The wood used in the first wheels was teak, which was saturated with oil and white-lead by a process similar to creosoting, *i.e.*, by placing the blocks in a receiver, first exhausting the air to remove the sap, and then forcing in the oil and lead under a pressure of ninety pounds to the square inch. Some of these wheels have lately been taken off and cut down to a smaller diameter; and the Author is assured by Mr. W. G. Beattie that the wood was perfectly sound. He was at the same time informed that the breaking of an axle had never been known to take place with these wooden wheels—a result which can only be due to the elasticity they possess. These wheels are lighter than ordinary iron wheels, the total difference being as much as 3 cwt. per pair; and their first cost is not much greater. The tires rest directly on the wood, so that no skeleton is required, and are of course secured by some kind of clip fastening, and not by rivets. This is not the time to discuss the vexed question of riveted tires; but it cannot, of course, be denied that a rivet-hole must make a weak place in any piece, especially one so heavily strained as a tire; and now that other fastenings can be provided at little extra cost, it may be doubted whether the time has not come for giving up the old system altogether.

In the sharpest possible contrast to the elastic wooden wheel is the chilled cast iron wheel so much in vogue in America. The merits of this have been more than once discussed in this place, and also the question of its manufacture in England. It is believed that there would be no real difficulty as to the manufacture, provided pig iron of the requisite purity were used. This would now have to be obtained from Sweden, Russia, or elsewhere; but should a demand arise, charcoal blast-furnaces (of which one still exists at Lorne in Argyleshire) would probably soon spring into being. The excessive rigidity of this wheel would certainly seem to form an objection to it; though this would appear not to have been felt in the States, where the permanent way is often of the roughest description. Possibly the curve which is usually given to the section between the boss and tire, in order to allow for contraction, may give to the wheel,

when in use, a certain degree of elasticity.

Before leaving the subject of wheels and axles, it should be noted that one important point to be aimed at is the prevention of the wear of the journals. The skeleton and boss of a wheel, and the whole length of the axle, are practically subject to no wear and tear whatever; and though tires wear out, they can easily be renewed. Thus the life of a pair of wheels would be indefinite were it not that the journals wear down, and the wheels are then useless. An obvious remedy is to "bush" them with brass or white metal; but as obvious an objection is, that the arm at which the bearing friction acts would thereby be increased. Another device would be to make the journals in separate pieces and screw them into the ends of the axles; but there might then be fear of their working loose. This point is one which would seem worthy of attention.

B. *Axle-boxes and Axle-guards.*—The next part of the wagon to be considered is the axle-boxes, involving the important question, whether oil or grease should be preferred as a lubricant. At present oil is universal in hot climates, is general in Germany and in the United States, and is largely used in England by railway companies; but grease is, in this country, almost the only lubricant used for private wagons. The advantages of the latter are its cheapness and facility of application. The real ground of its use is probably the much greater cost of an oil axle-box: thus Beattie's and Beuther's axle-boxes each cost about £5 per set, exclusive of royalty; while ordinary grease axle-boxes weigh less than 3 cwt. per set, and cost little over £3. The advantages claimed for the oil axle-box would seem to outweigh this difference in prime cost. These are: (*a*) The quantity of the lubricant used is so much smaller that it needs to be renewed very seldom. (*b*) Should the supply run short, the box heats, not suddenly, like a grease box, but gradually, taking two or three days to arrive at a dangerous temperature: this of course enormously increases the chance of its being discovered in time. (*c*) There seems no doubt that the friction resistance is decidedly smaller with oil than with grease, a point of vital importance. A comparison made some years back, between the vehicles of the Orleans railway, using oil, and those of the Lyons railway, using grease, did not prove any marked difference between the two; but in a comparison of this kind the result may be affected by so many other conditions that it must always be regarded with suspicion. On the other hand, the experiments of M. Vuillemin and others showed a great superiority on the side of oil; and these have been confirmed by experiments on the London and South-Western railway. The general result of these was that with oil the resistance to traction of a wagon in motion was only three pounds per ton, while with grease it was about nine pounds. On the other hand, the resistance of a wagon at rest to being started was somewhat greater with oil than grease, but the difference was not large (fifteen pounds and thirteen pounds per ton respectively). Should railway companies, as previously suggested, take in hand the repairs of all wagons running on their system, they would probably provide for the greasing as well, charging a moderate sum per annum, which owners (to whom greasing and hot boxes are a perpetual source of trouble) would in general be most willing to pay. It would then probably be much to their advantage to forbid the further manufacture of grease axle-boxes altogether, and settle upon some definite system of oil lubrication.

With regard to axle-guards, the W-shape, now universal, probably admits of no improvement. The thickness of the iron, $\frac{3}{4}$ inch, is also fixed by general consent. Its width, however, is generally, in the Author's opinion, excessive: on many railways $3\frac{1}{2}$ inches is still the minimum. It is believed that (where the iron is, as it ought to be, first-rate) a width of $2\frac{1}{2}$ inches is ample, even for the crowns, and that for the wings $2\frac{1}{4}$ inches is sufficient. It must be remembered that both the pulling and the buffing strains are transmitted through the body of the wagon; consequently the stress thrown on the guards by sudden stopping or starting is only that due to the momentum of the wheels and axle, weighing together about fourteen cwt. This can never be very great; and, even with the moderate widths now used by some railways, the

fracture of an axle-guard is almost unknown.

C. *Springs.*—It is remarkable that conical bearing springs are general in America, but are unknown in this country. A comparison between these and the common laminated springs would be interesting, but it has not been possible to obtain the requisite data for making it. The spring of the Highland railway is flat and long, like a carriage spring, consisting of nine plates 3½ inches by half inch; the uppermost three feet six inches in length. On other lines the plates have a decided camber; their width varies from four inches on the Caledonian to three inches on the Great Western, and whilst in the former case they are ten in number, each half inch thick, in the latter there are two plates ⅜ inch, and fourteen plates $\frac{5}{16}$ inch. A much lighter spring is that used on the Cambrian railway, which consists of ten plates 3 inches by ⅜ inch, and one plate 3 inches by ½ inch. Probably a simpler form even than this would suffice. In a wagon great flexibility is not necessary; and strength is best consulted by making the plates few and thick; since in a laminated body the several parts act almost independently, and the sum of their strengths gives the real strength of the whole. Hence, as the strength of a beam varies as the square of its depth, six plates ½ inch thick will more than equal ten plates ⅜ inch thick; and it would seem that a spring consisting of only seven plates 3 inches by ½ inch would have sufficient strength, and probably also sufficient elasticity. Such springs would not weigh above 2 cwt. 2 qrs. per set, in comparison with 4 cwt. 2 qrs. 20 lbs., the weight of Great Western springs.

D. *Underframe.*—An ordinary oak underframe for an eight-ton wagon. It may be worth remarking that the diagonals of the under-frame should always incline from the centre towards the buffers, and not, as sometimes seen, from the ends of the middle bearers towards the drawbar. In the latter case they give no assistance against the pull of the draw-gear, because they cannot act as ties; in the former they are able to assume their proper function as struts, and thus help to support the "buffing" strains.

This difficulty as to ties constitutes, in fact, the chief disadvantage in wooden structures. In an under-frame it compels the use of wrought iron tie-rods both along and across the frame. Looking at this, an under-frame of combined wood and iron would seem desirable, in which angle or T-irons should act both as supports and ties; but such combinations are rarely successful. Carrying the same idea still further, many engineers have built under-frames wholly of iron, but the advantage of this is more than doubtful. For on comparing the properties of American oak and wrought iron, as given in Rankine's Rules and Tables, p. 195, it will be found that the following is approximately true: a bar of iron in comparison with an exactly similar bar of oak has five times the strength to resist tearing, six times the strength to resist crushing, and four times the strength to resist cross-breaking; but, on the other hand, it has ten times the weight, and twelve times the value. Hence to have, say, a sole-bar in iron of the same strength as one in oak, one-sixth the scantling must be given; but in that case it would weigh 66 per cent., and cost 100 per cent. more than its rival. This result is completely borne out in practice. The weight of the oak underframe shown in the diagram is about 12 cwt. (including tie-rods, etc.); and its cost at present rates is about £7 12*s.* But an iron under-frame of the same general character and size, if made with the usual dimensions, would weigh about 16 cwt., and cost about £15 13*s.* Against so large a difference, there seems only one point to urge in favor of iron, and that is its greater durability. But this may easily be bought too dear. In the first place wagons get out of date. This was the case with the early railway wagons, which were soon superseded; and at the present moment a striking instance is afforded in the broad-gauge stock of the Great Western railway, which was built in the most durable style, but is now being in a great measure abandoned, or converted, at a heavy cost, to narrow-gauge. But apart from this, the ordinary life of a wagon is so hazardous, exposed to so many natural and unnatural shocks, that its average duration is much below what would be due to the ordinary processes of decay. On this

point, as might be expected, opinions differ much, and statistics are hard to obtain. The engineer of one important railway stated that the number of wagons destroyed by accident was so small as not to be worth consideration. The engineer of another line, equally important, held that on an average wagons did not run above twelve years before coming to a violent end. Probably the truth lies between the two. At any rate there seems good reason to conclude that durability is by no means the most important point in the designing of such a structure as a railway wagon; and, in fact, so fully has this been realized by some leading authorities, that on the vast system of the Midland railway, for example, iron underframes are completely unknown.

Another point remains for consideration, viz., the scantling to be given to the headstocks, sole-bars and middle bearers. They are all twelve inches by five inches, and this is the scantling fixed by most of the leading railway companies for private wagons. At the same time dimensions much below these are not unknown. There are six-ton wagons now running on the Swansea Vale railway whose sole-bars, &c., are only 9½ inches by 4½ inches. The Highland railway are content with 11 inches by 4½ inches, and the Caledonian railway with 10½ by 4½ inches. And it is specially to be remarked that those companies who insist most strongly upon the full dimensions in private wagons are yet often found to fall short of them in those they build for themselves. It was, in fact, admitted by a high authority that the full dimensions were not really necessary, but were retained to provide against the possible use by private builders of inferior materials. Even if requisite for the sole-bars and headstocks (on which the chief strains are brought), these dimensions would seem needless for the middle bearers. The reason for strengthening these was, no doubt, the fact that with ordinary draw-gear the whole strain of traction is brought upon them; but with continuous draw-gear this is not the case, and then these middle bearers (especially if the bottom planks run across, not along the frame) have but little to do. In any case, the model wagon may be assumed to have sole-bars and headstocks of 11 inches by 4½ inches scantling, and middle bearers and diagonals of eleven inches by three inches.

E. *Draw-gear.*—The draw-gear universally employed for wagons consists of a hook at each end of the truck, with a shackle and chain attached to it. This hook is welded on to the end of a bar (1¾ inches round in general), which passes through the headstock and generally also through the middle bearer, and is made to bear against the latter by means of a nut and indiarubber washers. An improvement on this is the continuous draw-gear, which consists in uniting together the inner ends of the two drawbars so that they form one system, and the traction is obtained by the drawhook in rear of the truck bearing against its headstock. It is clear that in the first case the body of the truck forms itself a link in the chain of traction, and the whole resistance of the hinder part of the train is transmitted through it as a tensile strain. In the continuous system, on the other hand, the drawbars form the chain, independently of the wagons, and the whole strain on any one of the latter is that due to its own resistance to traction, conveyed in the form of pressure which it is best adapted to resist. The disadvantage of the continuous system is its great weight and expense. The heavy drawbars, extending the whole length of the truck, do not add to its strength in the slightest degree, and the 'cradle,' or intermediate piece which connects the drawbars together is always cumbersome and costly. In view of this a system of continuous draw-gear has been designed. The indiarubbers are contained in a wrought-iron case fixed upon the outside of the headstock: and the strain is transmitted through four ⅞ inch rods, which at the same time act as the longitudinal ties of the underframe. The draw-hook terminates in a short shank which passes through the headstock to get an inside bearing. The advantages aimed at are: (1) A saving in weight and cost, since the ordinary tie-rods are dispensed with. (2) The avoidance of a weld in the drawbar, hence the risk which always attends a welded piece is absent. (3) The indiarubbers are outside the truck, and more easily accessible when required. (4) The strain is transmitted through four rods instead of one; and should one of these

happen to be of inferior quality and give way, the other three would probably hold, at any rate till the wagon reached some place where the failure would be observed.

Before leaving the subject of drawbars a word may be said upon safety chains. These, which were once in general use, have been mostly abandoned, for it has been found that if a drawbar breaks, the safety chains inevitably also break under the shock brought on them by the separating train. This, in fact, has so often been the case that their discontinuance is not to be wondered at; indeed, in more than one instance they have done actual harm by one of them holding while the other gave way, and thus getting the wagon across the line.

F. *Buffers.*—There would seem to be a growing inclination to abandon spring buffers—at least in mineral wagons: and this tendency, once begun, is likely to increase, since a wagon with spring buffers placed in a train of others having "dead" buffers only is sure to fare badly. In the more expensive class of wagons, such as are built by railway companies, the wrought iron buffer seems to be superseding the cast-iron.

The Midland railway and also the Great Western now build their wagons with a buffer system similar to that used for carriages. The buffer-heads are attached to long rods, which bear against the two ends of a large laminated spring laid horizontally across the underframe outside the middle bearer. The drawbar is widened out and a slot made in it, through which this spring passes, so that it acts against the traction as well as against the buffing strains.

G. *Body.*—The outside dimensions of the body are left in general to the judgment of the builder. The Taff Vale railway, however, specify that the capacity shall be between 240 and 245 cubic feet, and that the wheel base shall not be more than five feet six inches. This necessitates an exceedingly short and deep wagon. On other lines the wheel base is generally specified to be about eight feet, and the length, especially in the North of England, is at least thirteen feet, and often fourteen feet or upwards. The Author considers the Taff Vale type, though perhaps exaggerated, represents much more nearly what should be aimed at. The advantages of short wagons are manifold. In the first place, they effect a considerable saving in weight and cost. The sheeting is of course nearly the same in any case if the cubic contents are the same; but the sole-bars, side rails, and diagonals are shortened, and so are the drawbars, capping irons, and longitudinal tie-rods. Secondly, short trucks are handier in themselves, and require smaller turntables. Thirdly, they make up into shorter and handier trains. This is of great importance when the enormous length of goods trains at the present day is considered, and also that such a train has usually to move its whole length twice (first past the points and then over them) in order to get into a siding. Fourthly, a short truck cannot fail, as a long truck often does, by the 'hogging' of the sole-bars. Supposing a sole-bar to be uniformly loaded, and supported on axles eight feet apart, it may be shown that it should not overhang more than two feet ten inches at each end if the strain over the bearings is not to be greater than that at the center; but, considering the weight of the head-stock, buffers, and sheeting, &c., which are placed at the extreme end of the sole-bar, it would seem that two feet three inches is a more fitting limit. This would give a length of twelve feet six inches; and it is thought that this, with a width of about seven feet six inches, and a depth of about two feet nine inches, forms the most suitable body for an eight-ton wagon. If there are no end doors the two end planks may be curved with a rise of five inches, and then the depth at the sides need not exceed two feet six inches.

The thickness of the planking has also to be considered. In general that of the bottom is two and a-half inches, and that of the sides either two and a-half inches or three inches. The top edge is protected by a capping iron or flat bar. This bar is simply screwed down to the top plank, and does not add to the strength of the wagon in any way. It would appear feasible to transform this into a light angle-iron (say $2 \times 2 \times \frac{1}{4}$ inches) which should be bolted at each end to the corner plates (being let into the top plank throughout its length) and also to the inside knees wherever they occur.

There would thus be formed a sort of light wrought iron frame for the body, which would materially strengthen it, and the thickness of planking might then be reduced to two inches, or even less. The Caledonian railway even now employ planking only one and a-half inch thick, strengthened by stanchions and a top rail, it is true; but this seems sufficient to prove that the thinner planking would not suffer unduly from wear and tear.

The inquiry is now concluded. For an eight-ton goods wagon, embodying the dimensions, &c., arrived at for the several parts, the tare weight would be about three tons eighteen cwt. while the eight ton wagons now running weigh from four tons eight cwt. to five tons ten cwt.

Even so the proportion of tare to load (or of dead weight to paying weight) seems to be high; but the reasons stated at the commencement preclude the hope of the reduction being carried much further. It remains for the Author to express his obligations to several gentlemen connected with railways, both for valuable information and for drawings of wagons, many of which are exhibited: especially to Mr. Armstrong, of the Great Western Railway; Mr. Beattie, of the London and South-Western railway; Mr. Clayton, of the Midland railway; and Mr. Herbert Wallis, of the Grand Trunk railway of Canada. His aim throughout has been to raise points for discussion rather than to lay down authoritative rules, and with this understanding he now leaves the matter in the hands of the Institution.

RIVERS POLLUTION.

By JAMES P. KIRKWOOD, C. E.

Abstract of the Report to the State Board of Health of Massachusetts.

Part I.—Preliminary.

The law requiring the special information, and, incidentally, the examinations to be noticed in this Report, reads as follows :—

An Act to provide for an investigation of the question of the use of Running Streams as Common Sewers in its relation to the Public Health.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows :—

Sect. 1. The State Board of Health shall investigate, by themselves or by agents employed by them, the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth, especially with regard to the pollution of rivers, estuaries and ponds by such drainage or sewerage; and to devise and report a system or method by which said cities or towns may be properly drained, and said rivers, estuaries and ponds may be protected against pollution, so far as possible, with the view of the preservation of the health of the inhabitants of this Commonwealth, and the securing to the several cities and towns thereof a proper system of drainage and sewerage without injury to the rights and health of others; also, to report how far said sewage may be utilized and disposed of.

Sect. 2. Said State Board of Health, or agents employed by them, may enter upon and make surveys of lands, so far as may be required, and without unnecessary injury thereto, and said Board may employ such assistants, with the consent of the governor, as from time to time may be expedient. They shall report to the next general court, not later than the first day of February, eighteen hundred and seventy-six.

Sect. 3. The compensation of the members of said State Board of Health, or agents employed by them, for services under this Act, shall be fixed by the governor and council, which, with the expenses incurred by them, to be approved by the same authority, shall be paid by the treasurer of the Commonwealth, on the warrant of the governor.

Sect. 4. This Act shall take effect upon its passage.

The above Order has in view two important means towards the security and

improvement of the general health, one of which, sewerage or drainage, has long been pretty well understood, and to some extent acted upon; and the other, the maintenance of the purity of our running streams, has been in the United States as generally neglected.

Throwing together the sentences of the law which refers to sewerage, it requires the Board of Health "to investigate the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth," and to devise and report "how far said sewage may be utilized and disposed of."

In regard to the rivers of the Commonwealth, it requires the above investigation to be made "especially with regard to the pollution of rivers, estuaries and ponds by such drainage or sewerage," and to devise a system by which "said rivers, estuaries and ponds may be protected against pollution, so far as possible, all with the view of the preservation of the health of the inhabitants of this Commonwealth, and the securing to the several cities and towns thereof a proper system of drainage and sewerage, without injury to the rights and health of others."

In previous reports of this Board, particularly the fourth and fifth annual reports, the general questions of sewerage of towns and pollution of rivers have been very thoroughly discussed. In reviewing the same questions now, some repetition will be unavoidable; but, remembering what has been already said, and that the literature of the subject is now large and accessible, we will endeavor to condense what may require to be said again to meet the Act already quoted, and to further the objects which it has in view.

Without attempting to keep the subjects above defined separate, where they may naturally come together, the present condition of our rivers will first be looked at—how far they are polluted now, and the evils which that pollution entails, whether under ordinary or exceptional circumstances. To this end, as examples of the polluting exposure to which the rivers of the State are subject now, an exposure against which there is practically no defence through the common law, five of the river-valleys of the State have been examined, and an account taken in each case of all the points where sewage or pollutions of any kind enter the river, including necessarily all factories, the refuse fluids of which enter, and to that extent degrade, the waters of the several valleys. The fluid waters flowing from factories of all kinds will be seen to be the chief cause of pollution in the valleys examined, except the Blackstone; the animal sewage, being as yet but rarely concentrated, is not so palpable, but it is greater, probably, in the aggregate than can be made to appear in the statistics.

The sketches of the valleys attached to this Report will show to the eye their extent and general character, with the positions of the objectionable elements referred to. The statistics will be summarized presently; but, although the mere statement of some of them will sufficiently offend the cleanly instincts of most persons, there are others who will reasonably want to know whether the delivery of a certain amount of such polluting fluids or matters into a river-course necessarily renders that water unfit for domestic use, and injurious to health. The facts affecting this view of the case, to whichever side they lean, should be fairly presented.

It may suffice to refer to the Thames and the Lea, at London, as exhibiting both the apparent insensibility of the human stomach to waters exposed to a considerable measure of impurities, as well as its fearful sensitiveness under the use of the same waters (polluted, some would say, but lightly by sewage) during the prevalence of an epidemic.

It cannot be said that all rivers receiving sewage in any degree are unfit for use; for, of the rivers from which water is freely drawn for human use, there are very few that are not exposed to pollutions of one kind and another, even up to their sources. There is no such thing as pure water, even at the sources, nor anywhere except in a laboratory. Pure water, therefore, or good water, in ordinary parlance, is understood by the engineer to mean a palatable, wholesome water, not insipid like rain-water, and not open to the reception of that class of impurities which endanger the individual health. Palatable water will always have some foreign ingredient in it, which is not necessarily unwhole-

some; when pollution, therefore, is spoken of in connection with rivers, it refers to those kinds of impurities which, when known, should make the water repulsive for human use. That it does not always do so is the effect of custom, which gets men habituated to almost any evil which is ever present, especially when it cannot by an effort of will be promptly remedied. In this case, too, the evil is but rarely present to the senses at the point where the water is used; it is only known by common report.

The Second English Rivers Pollution Commission give the following as "the chief characteristics of unpolluted water: It is tasteless and inodorous, possesses a neutral or faintly alkaline reaction, rarely contains in 100,000 pounds more than one-half pound of carbon and one-tenth pound of nitrogen in the form of organic matter, and is incapable of putrefaction, even when kept for some time in close vessels at a summer temperature."

In our own country, we have the water-supply of Philadelphia to point to, taken from the Delaware and the Schuylkill, both at places where the water has been much exposed to pollution; and we have the water-supply of Cincinnati, taken from the Ohio River at a point very near to the largest and worst sewer of the city. In Philadelphia, at least, the effective pollution is probably greater than on the Thames, because the water is taken from the streams at points nearer to the polluting deliveries than on the Thames; though these deliveries may be much less in volume when compared with the general volumes of the streams which receive them.

On the Schuylkill, the aggregate of polluting fluids entering the river above Philadelphia is represented to be greater than on the Thames above London, comparing equal volumes of their waters.

We are presented with the same anomaly here that occurs when we compare the annual death-rate of London, under the exposed waters of the Thames and Lea, with the death-rates of other cities that are supplied with water purer in every way.

The latest statistics within our reach give the annual rate of mortality for New York as twenty-nine per thousand of the population, taking the average of the four years 1870, '71, '72, '73. The average of the same four years for Philadelphia gives twenty-three per thousand. But the Croton waters which supply New York are not exposed, except in a very small way, to any of the impurities which so markedly mix with the waters of the Schuylkill and the Delaware.

The populations of these two cities are somewhat different in general character. New York includes more of a foreign and a floating population, and is in some of the wards very densely occupied. A large part of its working population leave the city at night, however, and find cheap homes in New Jersey and Long Island, whereas the working population of Philadelphia remain within the city lines.*

The reports of the Board of Health of New York give the following as the annual death-rates per thousand, for 1871 and 1872 in the British cities named. I am not able yet to give the returns for 1873 and 1874:

* By the census of 1870, we have the following statistics:

Cities.	Total Population.	Per cent. of Foreign Population.	Total area of city in square miles.	Average population to each square mile.	No. of dwellings.	No. of persons to each dwelling.
New York....	942,292	.44	40.6	23,209	64,944	14.72
Philadelphia..	674,024	.27	122.0	5,525	112,266	6.01

The average density of population is considerably less in New York than in London, which has an area of 117 square miles, and had by the last census (1871) a population of 27,793 to the square mile. The average density of population in Liverpool is even twice as great as it is in London. Philadelphia has lately annexed a large area of country which is very sparsely settled.

	1871.	1872.
Liverpool	35.1	27.1
Leicester	26.8	26.8
Manchester	28.6	31.2
Edinburgh	26.9	26.5
Glasgow	32.9	28.4
Dublin	26.2	28.9

All of these English cities derive their water from grounds which are free from the polluting influences to which the River Thames is exposed, and yet the death rate of London is somewhat below that of any of these cities, being 24.7 for 1871, and 21.4 for 1872. This kind of comparison is necessarily imperfect, because in the manufacturing cities the population is more concentrated than in London, and the amount of deprivation and exposure leading to sickness and suffering probably much greater. The sewerage, too, of most of these places is still imperfect as compared with London. Still, under ordinary circumstances, it would seem to be plain that a considerable measure of impurity may flow into river-waters without sensibly affecting the health of the communities living on them and using them, under ordinary circumstances, provided that the water is drawn from points five to ten miles distant from where the poison enters the stream. The London water companies take their waters from the river at Hampton and Kingston; the sewages of Windsor and Eton enter the river some fifteen miles or more above these points; and, although the banks of the stream, particularly in the eddies, are said to show marks of the impurities which it has received above, its presence at Hampton, where the water is taken for the city, cannot be sensibly distinguished, or proven to have communicated to the water any dangerous qualities, under ordinary circumstances. For this condition of things (as now understood), we are indebted to the fact of the volume of sewage being very small compared with the volume of water in the river; the sewage must be so largely diluted as to have become almost an inappreciable quantity. To secure this dilution, it is obvious that, if the river be a quiet, slow-flowing stream, it might take ten to twenty miles to produce the required mixing; but if fast-running, or pouring over dams and falls of water, a much less distance would have the same effect. If we dilute urine with a sufficient quantity of clean water and mix it thoroughly, no chemist could detect the impurity; nor could it be shown to be dangerous in any sense, however disgusting the knowledge would be that it was there.

A larger measure than this, including trade impurities, probably exists in the Thames water now at the points where it is used; for at this date (1875) we are informed that Oxford, Reading, Abingdon and Windsor still pass their sewage into the river, although they have commenced sewage works which will in time more or less remedy the evil.

It was long thought that sewage was destroyed by running water, but now it is believed by chemists to be all but indestructible there, and to be rendered insensible, as already said, and inert, only by being mixed largely,—thoroughly diluted, in other words, with at least one hundred times its volume of good water. Sewage distributed over land is appropriated like manure by the vegetation which it finds there, but, passed into running water, it finds little or nothing there requiring its aid. In the one case, it is where it is needed; in the other case, where no profitable use can be made of it. In the still, clear water of shallow ponds, vegetation will often be profuse, protecting the water by such large floating leaves as those of the pond-lily from the hot rays of the summer sun; and in the clear pools of sluggish but pure streams, the vegetation along the banks will often be considerable; but in running water there is but little vegetation,—none, it may be said, if the water is turbid or foul. In running water, therefore, such as mostly prevails in the rivers of the State, the sewage flows on with but little absorption from the very few plants it meets.

It is not to be forgotten that the Thames water is very sensibly improved by the process of filtration to which it is subjected before being delivered to the city. This filtration does not merely remove the sediment which may be in suspension, but it removes a large portion of the organic matter (forty-seven per cent., Dr. Frankland says) which finds place in the natural waters of the river. In the comparison made above with other cities, it is to be noted that the waters of Manchester and Glasgow are

not filtered; the waters, however, of Leicester, Liverpool, and Dublin are filtered, and a portion of the Edinburgh supply.

In large cities, any measure of uncleanness and impurity will be submitted to by the poor and helpless; and until those who are better off are roused in their own interest, and for their own protection, to remedy this tendency, the foul taints engendered by the indifference to cleanliness which accompanies extreme poverty, as well as the inaction which belongs to it, will contaminate and render supine the rich; and, as in many European cities, both classes will have under their noses, it might also be said, a condition of things that could never be tolerated here.

If we look again to the Thames, the lessons from which are very marked, we are reminded that the very impure water delivered to the city before 1849 was borne with until the cholera appeared, and the fearful exaggeration of its ravages within the city was traced prominently, if it cannot be said entirely, to the character of the water used. How much mischief is done by the measure of sewage impurities which is drunk now with the waters of the London supply and the Philadelphia and Cincinnati supplies, cannot be known, so slow and insidious may be its effects on the constitution while no epidemic is present to bring the poison into daylight.

To understand fully the risk which follows the contamination by sewage, especially of potable waters, it will be necessary to review the cholera epidemics of 1849 and 1854 in London.

We are not able to make the kind of comparison that would enable us to understand the benefit to the health of a city population consequent on the use of entirely unpolluted water, as contrasted with the effect produced by the use of polluted water on the health of another population similarly situated. Such cases, in all respects similar, do not exist; but, from the water-history of London, the effect of using different measures or degrees of polluted water can clearly be traced. The cholera epidemics of 1849, 1854 and 1866 give very distinct lessons in this respect, and their histories, so far as they are connected with the water-supply, will therefore be briefly traced.

The metropolis of London is supplied with water by eight companies, five of which take their water from the Thames, two from the river Lea, a tributary of the Thames, and one (the Kent) from artesian wells in the chalk.

During the cholera epidemic of 1848–9, all the companies delivered their water to the city without filtration, the Thames companies taking from the Thames on tide-water, which was at that time subject to the entire sewage-impurities of the city, as well as of all places above it on the banks of the Thames, or of the Lea, which found it convenient to pour their sewage into these rivers or their branches. The epidemic of 1848–9 left the conviction—without, it may be said, absolute proof—that its severity was more or less due to the impurity of the water-supply, and a law was passed, in consequence, requiring all the Thames water companies to take their supplies from a point above tide-water and above London, and to have the water sufficiently filtered before delivering it to the city. A certain period of time was given the companies to make this change and to construct the proper filtering works. The cholera visitation of 1853–4 found certain portions of the city supplied with filtered water taken from the Thames above the city and above the influence of the tidal flow, and certain portions still supplied as before; some of the water-companies having managed in the interim to change their point of in-take to a position up the river, beyond the influence of the sewage of the city, having made provision at the same time for the settling and filtering of the water; while others of the companies had not yet effected the required change of location, nor completed the necessary filtering works.

This cholera epidemic of 1853–4 showed very distinctly that in those parts of London where the filtered water taken from above the influence of the sewage of the city was used, the epidemic was very much less malignant than where the more impure water was used, taken from within the influence of the sewage of this great city. The General Board of Health took some pains to gather the statistics illustrative of this fact. Mr. J. Simon, F. R. S., in his report to the Board, made in May, 1856, selects the two water com-

panies for comparison which were supplying the same class of houses, and as near as may be the same kind of population; the pipes of the two companies for a portion of their districts being laid in the same streets, each supplying about the same proportions of the houses in these streets. The one, the Lambeth, was delivering, in 1853–4, good water, speaking comparatively, from the Thames at Ditton; the other, the Southwark and Vauxhall, delivering bad water from the Thames at Battersea, as in 1848.

"Commonly, in attempting such inferences, the inquirer is baffled by difficulties which render exact conclusions impossible; for populations drinking different waters will often be living in different circumstances of wealth, comfort, occupation, cleanliness, soil, climate."

"In reference to the comparison which had to be made, it is especially important to observe that the tenantries of these two great companies were not set on different parts of the South London area, each isolated from the other. On the contrary, the two populations were, so to speak, mutually interfused. Of thirty-one sub-districts into which the large space is divided, only eight were monopolized by a single water company; while of the remaining twenty-three, each was supplied sometimes in equal proportion by one company and the other."

"In the 24,854 houses supplied by the Lambeth Company, comprising a population of about 166,906 persons, there occurred 611 cholera deaths, being at the rate of thirty-seven to every 10,000 living. In the 39,726 houses supplied by the Southwark and Vauxhall Company, comprising a population of about 268,171 persons, there occurred 3,476 deaths, being at the rate of 130 to every 10,000 living."

"The population drinking dirty water accordingly appears to have suffered three and a half times as much mortality as the population drinking other water."

"But this evidence is only a part of the case; it admits of being greatly strengthened by a second group of facts which the statistical tables exhibit. It was thought proper to see how far any discoverable influence of foul water had been constant to both occasions; and this comparison is of singular interest for our purpose, because the Lambeth Company, which in 1854 gave the superior water, was in 1848–9 purveying even a worse supply than that of the Southwark and Vauxhall Company."

"It has already appeared that the tenantry of the Lambeth Company lost by the epidemic of 1853–4 611 persons. By the epidemic of 1848–9, in the same houses (or rather in as many of them as then existed), the deaths were 1,925."

"The earlier figures showed that this population suffered in 1853–4 not a third as much as its neighbors; the present figures give the further fact that it suffered also not a third as much as at the time of its unreformed water-supply."

"Since the epidemic of 1853–4, the Southwark & Vauxhall Company, in obedience to the Metropolis Water Act, has abandoned its former very objectionable source of supply, and for the last few months [May, 1856] has been distributing a water nearly or quite identical in quality with that spoken of as furnished by the Lambeth Company."

"It entirely consists with the facts here set forth to maintain that, under the specific influence which determines an epidemic period, fecalized drinking-water and fecalized air equally may breed and convey the poison, and that this, whether in one vehicle or the other, may be expected to prevail most forcibly against the feeble and ill-nourished parts of a population."

It may be added that the evil effects of much-poluted water as compared with water but little polluted, which become so palpable and distinct in a time of epidemic, cannot cease to exist except in degree when no epidemic prevails. According as the river-waters are cleansed from the impurities which now are expected to hide themselves there, the general health of all living things depending on them and using them, whether in the shape of drink or food, must be benefited.

The cholera reappeared in London in 1866, June, July and August, and called attention again to the character of the water-supply by the "explosion," as it was called (from the sudden and fearful increase of deaths), in that district of

London supplied from the pipe-mains of the East London Water Company.

This company derived its water from the River Lea, at a point above Tottenham Mills. The water there passes into large open settling reservoirs. Moving slowly through these, and depositing there the heavier portion of any impurities in suspension, it is carried by an open canal about three miles in length, to the filter-beds below Lea Bridge. After filtration it is carried by a four-foot pipe, two miles in length, to the pumping station at Old Ford, where it is received into two covered reservoirs in communication with the pumping engines there. It is to be noted that there is one large pumping engine at Lea Bridge on the site of the filter-beds. At Old Ford there are four pumping engines.

"Of the total mortality from cholera in this visitation, of 5,548 souls, no less than 3,909 occurred in the East Districts alone." The population in this case will be a better indication of the condition than the relative area. The population of London for 1866 was 3,037,991; the population of the East London Districts was 598,945, leaving 2,439,045 for the rest of the metropolis. "No relative development of like magnitude, suddenness and shortness of duration has occurred in previous outbreaks of cholera in the metropolis." Nor are we able to trace the great excess of deaths to density of population. "In the recent outbreak, as in previous outbreaks, there was no relation between the density of population as expressed by numbers of persons per acre and the intensity of prevalence of the disease."

The following table shows the weekly deaths:

(*See Table next column.*)

CHOLERA OF 1866. WEEKLY DEATHS.

Week ending—	In the East District (598,945 population).	In the rest of London (2,439,046 population).
July 7	9	5
" 14	20	12
" 21	308	38
" 28	818	86
Aug. 4	916	138
" 11	673	108
" 18	369	86
" 25	198	67
Sept. 1	122	76
" 8	74	83
" 15	77	105
" 22	56	94
" 29	55	122

The exaggeration of the death-rate over the ground supplied by the East London Water Company led to the suspicion that the water must be in fault. At Old Ford, beside the two covered reservoirs receiving the filtered water from Lea Bridge, there were two uncovered reservoirs full of unfiltered water; that water being likewise decidedly more impure than the water drawn from the Lea at the point of intake four miles up the river. The water in these uncovered reservoirs was drawn in part directly from the Lea near by, by soakage. "The river at this part of its course, in June and July, 1866, was a cesspool as well as a canal, for it then received the sewage of the large population inhabiting Old Ford, and the greater portion of Bromley and part of Mile-end." One of the covered reservoirs had a connection with the open reservoirs, and when the filtered water was deficient, the unfiltered water could be drawn from the open reservoir to meet the requirements of the pumps. It was ascertained that some water from these open reservoirs had been used, and to this mixture of a water, which, beside being unfiltered was in other respects much less clean, with the ordinary supply, this exaggeration of the cholera in this district was ascribed. The amount of bad water used seems to have been small, and yet the effect was fearful. Mr. Radcliffe believes that the fecal discharges from some cholera-patients emptied into the Lea there, reached and affected the waters of these open reservoirs.

In corroboration of the belief that the water at Old Ford was contaminated in this way, and was the cause of the explosion of disease, the water delivered by the pumping engine at Lea Bridge, drawing its water directly from the filter-beds, did not produce this effect over the ground supplied by this engine.

The mixture of impure water at Old Ford had occurred frequently before with no perceptible effect on the population supplied. It was only on the occasion of an epidemic that the additional im-

purity made itself understood. Have we not reason to infer again that, as the waters furnished to London become less polluted than they are now, the general salubrity of the place will markedly improve, and the visits of an epidemic become less and less severe?

All that has been said thus far, although at times apparently contradictory, may be epitomized as follows:

To those who are willing to risk a certain measure of river-pollution, and who would disregard the warnings of epidemics, the London supply from the rivers Thames and Lea, can be referred to and quoted as being sufficiently safe for all uses, in healthy times, and under careful management and filtration, not withstanding the pollutions to which these streams are known to be exposed.

To those on the other hand who would not expose the public health to any risk that can be avoided, and who believe that the gradual emancipation now in progress of the rivers Thames and Lea from sewage and other impurities will certainly improve the health-rate of that metropolis, and defend it measurably from those exceptional visitations of sickness, from which we can never expect to be wholly exempt;—to such, it is believed that the same course, as far as practicable, should be pursued with regard to the rivers of Massachusetts, and that pollutions of all kinds should be, as far as possible, prevented hereafter from passing into them, and that the fluid pollution now flowing into them should be intercepted and deodorized as far and as speedily as may be practicable; so that the waters may be gradually restored, and held, to that amount of cleanliness at least, which will admit of their being used as fair river waters are used in the arts and manufactures, in which fish will live and thrive, and which animals will not refuse, although the restoration might not always be sufficient to make the water safe for domestic use.

It is to be remembered of the rivers that rise within the State, that their waters are small in volume as compared with the Thames River. They have, besides, more fall per mile; present more frequent opportunities for water power; are much more occupied generally by mills for their volumes of water, and will therefore have a denser manufacturing population on their banks. The refuse from the various fluids of factories may be expected speedily to render these rivers (of small volume in summer) unfit for use, and in this respect far below the standard of the Thames water.

Some of the smaller rivers in England, as the "Ribble," and the "Calder," have run this course, are now black from manufacturing pollution, and have been long unfit for any domestic use.

Part III.—General Conclusions.*

In comparing, as has been done, the waters taken from the head and foot of each river, so to say, and from intermediate points, the inferences which have been drawn, or which could be drawn, from these chemical examinations, are not to be considered as expressing the whole truth; but only that part of it which analysis can reach; the exact influence or even presence of the sewage and trade-pollutions which may have passed into a stream cannot be discovered by the chemist, when minute in quantity. The poisons may be so largely diluted as to be beyond the readings of analysis, and yet they may be sufficient, when fairly presented and understood, to render the water, by reason of that knowledge, not merely repulsive or suspicious, but more or less dangerous for family use.

The opinion of the English Rivers-Pollution Commission was very decided on this point at the date of their writing (1868): "No process has yet been devised of cleansing surface-water once contaminated with sewage, so as to make it safe for drinking." And again: "Among the numerous processes for the cleansing of polluted water with which we have been acquainted, there is not one which is sufficiently effective to warrant the use for drinking of water which has once been contaminated with sewage or other similar noxious animal matters."

If this view of the case may seem to be over-cautious, it is to be remembered that the poison, however trifling, is taken daily, and that although when in robust health the individual will not suffer from it, it may be sufficient to make itself felt when he is prostrated by sickness

* The portion of the Report which presents the results of examinations of Rivers and Ponds is necessarily omitted for want of room.

and his powers of resistance to such influences are then proportionally impaired.

We have therefore, as Dr. Frankland says, always to ascertain and keep in view the character of the stream as regards exposure to pollution, and, if it has received much filth in its course, to consider its waters objectionable and to be avoided if possible for human use; unless, indeed, the volume of the stream should be so great, compared with the filth-pollution, as practically to be independent of such reasoning.

As an instance confirmatory of these remarks, take the water of the Blackstone River at the point where it crosses the state line, near Blackstone.

The river reaches this point, carrying with it the sewage of the city of Worcester, the refuse waters of thirty-six woolen mills, twenty-three cotton mills, six iron-works, a tannery and a slaughter house,—these works employing 7,200 hands, much of whose ablutions and sewage passes into the river.

The sewage of Worcester may be taken at a minimum per day of	2,000,000 gals.
The sewage of the mill operators and their families, at	36,000 "
The fluid refuse of the mills it is difficult to estimate even approximately; it was estimated by the assistant engineer at 2,678,000 gallons—say,	2,500,000 "
Gallons per diem	4,536,000

Equal to 606,508 cubic feet per diem.

At Blackstone, the dry weather-flow of the river is taken at 5,961,600 cubic feet per diem.

This last includes the polluted waters as above estimated. We have therefore in this case, 5,355,092 cubic feet of unpolluted water mixed with 606,508 cubic feet of badly polluted water.

The sewage and refuse waters delivered into this river amount, then, by this estimate, to a little over ten per cent. of the average dry-weather flow of the stream at Blackstone, a degree of contamination which will be admitted to be condemnatory of that water; but, when the sample of water was taken for analysis (July 10), the river was not at its lowest summer stage, which generally occurs much later in the season. The flow in the river was not gauged at the time that the sample was taken for analysis, but its rate at that time might probably be about double of the dry-weather flow of a low season of rainfall, which would reduce for that date the proportion of the Worcester and trades sewage to over five per cent. of the volume of water running at Blackstone.

None of the rivers examined by us have this season reached the low stage of water referred to; they have all been in a low summer stage when the samples of water were taken, but not exceptionally so; and yet this exceptionally low stage must be encountered, sometimes for months, during very dry years. The pollutions received must, then, be applied to this measure to understand the degree of foulness to which the stream will be subject, noting, however, that during the very dry stage referred to, while the pollution from sewage will not be reduced, the pollutions from trades' refuse will be diminished considerably, whenever for want of water the factories are obliged to intermit or work half-time.

The analysis fails to show much difference between the water of the river at this point and its head waters—not enough to condemn the water for domestic use or any other use; but if you mix five per cent. of sewage-water with ninety-five per cent. of unpolluted river-water, the chemist could hardly fail, we should suppose, to discover some evidence of pollution. If this be so, we cannot avoid the inference, notwithstanding what has been said, and notwithstanding the opinions of eminent English chemists, that in the course of its movement over some twenty miles of the river channel, the sewage fluids in this case have lost some of their impurities, and that the analysis is not entirely at fault in encouraging this inference.

Of our rivers enough has been said, now and heretofore, to show that any defence of their waters against the impurities which so conveniently flow into them from the settlements and works on their banks, has thus far been merely nominal; that is, the law can be used to prevent a nuisance from continuing to be poured into the river, but it is not used because the process is too slow, cumbersome and expensive.

To change this state of affairs, and to

remedy it radically, is the problem now presented; and, while those who have been obliged to study the subject are confident that it is not insoluble, it is full of that kind of difficulty to overcome which will demand great perseverance, some experimenting, and, it may be, considerable invention and ingenuity. Not that there has not been much done in Great Britain to give direction to whatever may have to be done here, but our severe winter climate presents a difficulty by itself which will require special treatment; and, while there appears to be nothing insurmountable in dealing with it, it will probably add to the expense of all the purifying processes necessary to meet the different kinds of pollution to be dealt with. Every process will have in some degree to be tentative on this account, until the simplest and most economical mode of meeting the case is reached.

The Prevention of Pollution.

The law requires the Board of Health "to devise a system by which said rivers, estuaries and ponds may be protected against pollution, so far as possible, all with the view to the preservation of the health of the inhabitants of this Commonwealth."

To devise and perfect a system as varied in its modes of action as the fluid impurities emanating from the different kinds of works and from ordinary sewage will require, must, as has been hinted above, be a work of time; and, while authority must be lodged somewhere to begin this work, and probably to expend some money in ascertaining sometimes how to begin, it seems obvious that the authority given, should, in fairness to cities and manufactories, be exercised in the first instance only conditionally, and that in the case of any fluid impurities requiring to be stopped from entering the stream and to have their poisonous qualities destroyed, and the residue rendered innoxious before being passed into the stream, the authority having the power to require this course should be required to show how it can be done, and the apparatus or material required to effect it. In other words, that authority must be prepared to indicate or teach the mode of purification before taking legal action against it, the party required to act in the particular case being, however, at liberty to follow any process which he may prefer having in view the same end.

It may be further remarked in this relation, that the authority indicated should have the power to interfere with the pollution by steps, if advisable, perfecting such processes thereafter as circumstances admit of it. This might operate better than attempting that thoroughness of purification which may be practicable at once, inasmuch as entire purification will not probably in any case be attainable.

It may seem out of place in this paper to notice this phase of the subject, but its consideration is not easily avoided, and the allusion to it grows naturally out of the subject.

As an instance of the kind of difficulty which will have to be studied and overcome, the application of sewage to irrigation may be mentioned. Of all the modes of dealing with sewage, this may be said to be the favorite, inasmuch as it undertakes in a more simple way than any other to apply the fluid sewage upon land so as to make it as largely remunerative as possible. But there are two kinds of irrigation in this connection—the irrigation which, whether using water or sewage, applies it to the crops only as required and in quantities calculated to produce the best results. This kind of irrigation may be said to be always profitable; but, in this case, what is not wanted is not purified, and the overplus of that which has been used is not purified, although it has been somewhat deprived of its noxious qualities.

The other kind of irrigation is that which has in view, not merely the utilization, but also the absolute purification of the sewage-water. In this case there must be, first, such a liberal extent of land provided as will admit of the sewage during the growing season, at least, being entirely used by the different crops, arranged to that end. The process of irrigation, to produce the best results, being always intermittent, the grounds are broken up into many divisions or plots (the circumstances prescribing their size and number), so that the sewage-fluids can be transferred at will from one plot to another, or from one kind of crop to another; and there would want to be

some idle plots, so to say, upon which the sewage could be thrown at seasons when it was in excess of what the growing or maturing crops required. The reader will understand that in the process of irrigation a certain portion of the fluid will settle into the ground; and it is desirable that the ground should be of such a free and open character as to admit of this and to encourage it; for it is this earthy filtration supplementing the action of roots of the growing crops which deprives the sewage of its noxious qualities, and renders what is left of it fit to escape into the neighboring brook or stream. If this character of ground is not present, if the irrigation field has a heavy or clayey soil, deep drainage will enable it to produce the same cleansing effects; but the ground must be high enough to admit of this drainage-water, thus purified, escaping freely into some neighboring stream. To this, the most favorable view of irrigation as a means of entire purification, there are two exceptions, and under a negligent manipulation of the process there would be more; these are, first, the storm waters, which at certain times will make the delivery through the sewers so large as to render any reasonable extent of irrigation-fields incompetent for the time being to meet the excess, which cannot be allowed to flood the field, but must be otherwise taken care of; the second exception is the winter, when for some months, it may be, the irrigation-fields will become useless as such. Beginning with what can be done, the difficulties which these exceptions present will gradually solve themselves, and it would be needless now to speculate upon the precise way in which this will be accomplished.

Dr. Folsom's report of how this has been met in Northern Europe will throw some light on the matter. When a beginning is made, however imperfectly, the necessities of the case will create the ambition to remedy what is amiss or incomplete, and some satisfactory solution of this difficult problem will in all probability follow.

It will be thought by some that in the winter the sewer-fluids might be passed into the stream without rendering its waters so objectionable as in summer; but the reverse is said to be the case: the gases which escape from the sewer-deposits in summer from over the entire surface of the stream are sealed up in winter, so that by breaking a hole in the ice the bad odor is made perceptible by this kind of concentration in winter, when in summer the sense of smell does not reach it under ordinary circumstances. The winter water is therefore more dangerous than the summer water except that, there being generally more water flowing in the river then, the poisonous fluids entering it will be more diluted.

It is probably true that no process or combination of processes for the sufficient purification of sewage-waters has ever produced results which collectively made it remunerative; the precipitate collected by most of the patent processes will always sell for something for farming purposes, and where irrigation is used besides, crops will be large and have commanded good prices, but the adjuncts (whether of land for filtration or otherwise) necessary to destroy the whole of the filth more than eat up the profits. It is a great advantage and encouragement to be able to reduce the cost of this kind of purification; but to attain the desired result without any outlay, far less to make it a means of profit, is not, in the present state of our knowledge, to be expected.

The ground below Worcester is understood to be very favorably situated for irrigation, and the soil and subsoil to be of the right character as well for filtration. There will be a good opportunity, then, to deliver the Blackstone River from this its greatest concentration of pollution, and to experiment on the kinds of winter appliances that will be necessary in combination either with irrigation or filtration.

Drainage and Sewerage.

We now come to the second branch of the subject in the order in which it has been presented here, although in the discussion of the first it has been impossible to avoid touching on the second.

The law requires the Board of Health "to investigate the subject of the correct method of drainage and sewerage of the cities and towns of the Commonwealth, and to devise and report a system by

which said cities and towns may be properly drained."

To devise a system which, within the compass of a report of this kind would be applicable in its details to all cities and towns would be impossible; every city or town must be the subject of a separate study by a competent engineer, founded on a correct and minute survey of the streets or ground to be drained or sewered, with correct levelings of the whole.

The law evidently did not intend this construction to be put upon it, but it may have expected that some general principles should be presented controlling this part of the subject. Such general principles will govern each case, but to prescribe any special mode of carrying them out might be burdensome where all the State is interested in the result. Some points, however, may be noticed that are independent of any particular working system, or common to all of them.

In Europe, the drainage of the subsoil by a separate provision of drains, apart from the usual system of sewers to carry off the house-refuse, has been advocated, and there may be places where from the character of the subsoil or the amount of water present in it, such a double system would be desirable; but it has not found favor in this country, nor are we aware that it has been anywhere found necessary;* the increased cost of any such double system, and the inconvenience to the streets growing out of its proper maintenance, would always be barriers to its adoption.

The proper drainage of the soil is always very important, but, except where the water is held up by a neighboring river or lake or by tide-water, the trenches made for the sewers in our cities evidently act more or less as blind drains to keep it down.

This drainage of the subsoil, following as it frequently does the construction of sewers, if obtained at all through that defective construction which admits of leakage *into* the sewers, will do no harm while that leakage is moderate in amount, and consists of subsoil water escaping *into* the sewers. But the engineer will note that the same defective construction would admit of leakage from the sewer into the subsoil, when the subsoil-water happened to get below the level of the sewer, and that in this case the evil following a leakage outward would be twofold : the subsoil would be rendered filthy and might infect the neighboring cellars, and the fluid necessary to the flow of sewage-matters, if lost in this way, would lead to deposits within the sewers of the heavier matters, very objectionable there in every way.

For the continued and perfect action of the sewage, therefore, under all circumstances, the sewer should be so constructed as to be tight, and not leaky, unless the circumstances make the other course very clearly desirable. It is not difficult to make concrete sewers tight, if made with Portland cement concrete, or its equal; nor is it difficult, with proper attention to the joints, to make a pipe-sewer tight, nor a brick-sewer, if the engineer is determined to have it so.

The neglect of deep-soil drainage in the country at farm-houses, isolated dwellings of any kind, or villages, must be the cause of more sickness than any defects in the condition of the waters used there. In cities, the sewer-drains, or trenches, which are always deep, to some extent, take care of it, and, where they do not, the damp or wet cellars make the danger known, and show the necessity then of some separate provision to keep down the subsoil water. In those streets of a city which lie on a river bank, subject to floods, or upon the seaboard, as Boston, where the tides rise from eight to ten feet, both the drainage and the sewerage, as ordinarily provided for, are liable to serious interruption; in the first case, irregularity; in the second case, daily. To provide, if possible, for the uninterrupted flow of the sewage, is always important. It is very important that that flow should not at any time be brought to rest, because then the heavier portions will become deposited, and will accumulate and fester so as to generate the dangerous gases which belong to putrid sewage, but which in the case of fresh sewage are merely offensive. It is desirable always that the sewage generated in a city should leave the city on the same day, within twelve hours at most, and that it should never be retained long enough to become putrid. The drainage

* It has been used for some years in three towns of England.

in such exceptional cases would be a more difficult matter, and it would probably be cheaper in most cases to keep all streets and dwellings situated well up above tidal influences, than to attempt to keep down the subsoil water. But the interruption of the sewage-flow is another matter; it leads to a filthy deposit growing with each day, and which cannot be removed by the rate of original flow which would have kept it in motion to the pump-wells, and prevented its deposit. If it is allowed to subside and get firm, it can only be carried off thereafter at intervals by storm waters, or by flushing, or by manual labor; in either case after it has become very offensive. Under such a state of things, ventilation becomes very important. It is conceded that the impure air of sewers should rather be allowed by frequent shafts to escape into the street, than be driven into the houses, as it will be more or less, if no other *outlet* is provided for it.

Of the sewage proper, the Board of Health is required "to report how far said sewage may be utilized and disposed of."

The utilization of sewage by irrigation has already been dwelt upon, and the auxiliary works which may have possibly to accompany irrigation wherever the intention is as well to render the sewage-fluid, or its residues innocuous.

The utilization separately of the precipitates from sewage has been and is in many patent ways accomplished, but the fluids are not entirely deprived of their baneful qualities, and are reported to be unfit to pass into a river. None of these processes are remunerative when the other condition of rendering the fluid residue sufficiently pure as well as clear is insisted on. It is to be remarked of all these precipitates from sewage that, except when mixed with lime or some other equally valuable ingredients, they are all but worthless for manure. To make them salable for agricultural purposes, they must be enriched with foreign ingredients, without which the offensive solids of the sewage could not be got rid of.

The attempt is being made in some places on the continent of Europe, with a good deal of success, to keep separate the human excrements, and not allow them to enter the sewers, withdrawing them separately from the houses while fresh, and in various ways preparing them for agricultural use. It is obvious that if this could be accomplished, the kitchen fluids, the trades and the street refuse would be somewhat more easily and more willingly dealt with. The human refuse, although trifling in *degree*, compared with the mass of fluid which flows through a sewer, is yet sufficient to give it much of its offensive character, and to produce, when the sewers are neglected, many of the offensive odors and gases that are believed to be dangerous to health. The separate mode of disposing of human excrement is, however, repugnant to our habits here, and therefore, both here and in Great Britain, the water-closets and the removal by water of all human refuse is greatly preferred.

The most successful modes of dealing with sewage at this date, as well as with other pollutions which at present are rendering the waters of our streams so objectionable, are explained in the separate report of Dr. Folsom, who has devoted the past season to an examination of such operations in Europe. When it shall be necessary to act, we have thus the benefit of a large and varied European experience. Much of it can doubtless be assimilated here, with such additions or modifications as will meet the rigor of our winter climate.

LOCOMOTIVE TORPEDOES.

From "The Engineer."

One of the most remarkable phases of modern warfare is the employment of mechanical powers to transport explosives to the precise locality where they can prove most mischievous to an enemy. In the days of Nelson, ships fought with carronades, stumpy guns of considerable calibre, which pounded the wooden walls of a ship to atoms by a hundred blows. The duty performed by the Victory's

artillery was identical with that performed by a Roman battering ram. In the field, again, Napoleon relied on the round shot, which, as we are graphically told by the historians of the time, mowed lanes through the columns of an advancing foe. Grape was used at sea, or on land, only at close quarters. It was practically useless in naval warfare, save in resisting boat attacks, or covering the landing of troops, while its short range and unequal dispersion greatly limited the scope of its powers when it was used in land battles. To the American general Paixhans is, we believe, due the credit of first employing shells in naval warfare. In saying this we do not forget the labors of Cohorn, and we are not oblivious of the circumstance that "bomb ketches," as they were termed, existed and were used from a comparatively early period. But to General Paixhans belongs the credit of using guns which threw shells directly into a vessel without going through the ceremony of first letting them rise high in the air, and then fall, if chance so directed, on the deck or down the hatchway of a ship. The process of development has gone on steadily for very many years, and modern naval artillery relies principally on the effect of shell fire for its efficiency.

The 80-ton gun, for example, would be comparatively a very useless weapon if it could project against our enemies' ships only solid shot. A mass of iron weighing 1700 lb. tearing through a ship's side above the water line, and clear of engines and boilers, would do but little injury, save of a purely local character; and a great many successful rounds would have to be fired from the great gun before even a wooden ship to which the weapon was opposed need succumb. But in point of fact the chilled shell proper contributes only indirectly to the destruction which a heavy gun can accomplish. The object and purpose of modern naval artillery is to transport from the decks of one of our own ships to the decks of an enemy a heavy charge of powder, which is ignited at the moment of its arrival. If the shell explodes outside the ship, although in contact with her, half its efficiency is gone. A shell, after all, is but a transport wagon carrying a charge of powder; and that shell and that gun are the best which place the transmitted charge of powder just where it can be exploded with the most effect. It will be seen, therefore, that we have here a total change in the purpose of artillery; and it follows that if the explosive could as well be put on board an enemy's ship by any other means as by the use of a gun, then guns would be comparatively useless. The shell is *the* great engine of modern warfare. In olden times the gun took the place. The modern gun is, however, merely an energy transmitter, and in so far it occupies a secondary position.

A little reflection suffices to show that we are not confined to guns as the only means of transporting explosive charges to an enemy's decks. Various other plans have been suggested. The late Lord Dundonald proposed during the Crimean war that about a gallon of chloride of nitrogen should be carried up over Sebastopol in a balloon and then suffered to fall into that town. The resulting explosion would, no doubt, have cleared Sebastopol, its fortifications, and its fleet, off the face of the earth. The scheme was wild to the last degree. The explosion of a single drop of chloride of nitrogen has been known to completely ruin a large laboratory; and it is tolerably certain that more than a few drops of the most terrific compound that has ever existed have never been made. The use of balloons for dropping shells into an enemy's camp has often been proposed, however, and not many years since a somewhat eminent authority suggested the use of an improved form of the old Roman catapult for flinging grenadess and small shells into an enemy's trenche. Powder wagons provided with a slow burning fuse have been purposely suffered to fall into the hands of an enemy, who, removing the wagon to his own lines in triumph, has subsequently suffered severely for his rashness. Such a practice would hardly, we may say for the credit of humanity, be recognized as legitimate in modern warfare, although there is reason to believe that infernal machines assuming the form of blocks of coal have not only been suggested, but actually manufactured. The diabolical scheme of Thomas, which must be fresh in the memory of our readers, supplies another method of placing explo-

sives on board a ship or in some other locality where they are intended to effect destruction. All such schemes, however, have hitherto possessed but a fifth-rate importance as compared with the gun, which above and beyond all other agencies puts in the hands of the sailor or the soldier the means of lodging his shell just where he pleases. There is reason to believe, however, that the gun will not retain this absolute and overwhelming supremacy; and indications are not wanting that in the immediate future means will be provided of effecting all that the heaviest gun could accomplish in this way and a little more. We allude, of course, to the locomotive torpedo—a weapon with probably a great future before it.

So long as the torpedo was an anchored submerged buoy its utility was limited. The ship which it was intended to destroy had to go to it, and so long as it was left alone it would do no one any harm. The Harvey torpedo and the steam torpedo boat both enormously increased the power of the weapon; they each conferred on us the power of transmission; it became possible to take Mahomet to the mountain, as the mountain would not go to Mahomet. But it is obvious that very grave objections exist to both systems of attack. The torpedo launch can only be manned by volunteers who go on a forlorn hope. Not only can they expect no mercy from foes whom they must, in the nature of things, attack insidiously, but they run the risk at the best of times, when they are most successful, of sharing destruction with their enemies. The vessel towing a Harvey torpedo is again in much the same plight, and it is probably true that if several ships were operating together, the use of a Harvey torpedo by one ship might severely hamper the movements of her consorts, who would be compelled to give her a tolerably wide berth. The so-called fish torpedo promises to fulfil every condition that an engine of the kind can be called upon to perform. It is truly a locomotive torpedo, and is the most recent embodiment of the system of carrying on board—or into immediate proximity with a foe at a distance—the explosive charge which is to work her destruction. We say this with a perfect cognisance of the imperfections of the Whitehead torpedo. But we are, at the same time, in possession of facts which tend to show that it is susceptible of very important and valuable improvements. A great deal of money has been expended by the British Government on the invention since it came into their hands; and although a very commendable spirit of reticence restrains the official pen, enough is known to enable us to say that the range of the weapons has been so enormously augmented that it probably equals that of a very heavy gun, instead of being limited to a mile or so, while the difficulties which have been encountered in guiding it appear to be one by one disappearing in the hands of the intelligent officers who have charge of the invention. The Whitehead, or, more strictly speaking, the Woolwich torpedo, is now really a submarine boat, some twenty-five feet long, capable of running a distance as great as from Portsmouth to the Isle of Wight, the direction of its motion in still water being practically a right line.

It is evident, therefore, that for harbor attack it can probably be used with tremendous effect under certain circumstances. Thus an ironclad, by taking up a position at the mouth of a large harbor, and at such a distance that she would be practically safe from the guns of land forts, might, by sending in fish torpedoes, completely destroy a fleet taking refuge under the guns of the forts. The weapon might also be employed for clearing ground torpedoes out of a channel. In such a case it would assume a far simpler and cheaper form than that given to it when used to carry an explosive charge. The great difficulty to be overcome is to give it the power of always moving straight forward, exactly in the direction in which it should go; and this has been partly accomplished by very ingenious apparatus depending for its operation on the inertia of a suspended mass. It would be quite possible to use a gyroscope for the required purpose, but the difficulty would remain that if the deviating force be greater than the inertia provided can overcome, then the torpedo will assume a new line of motion, and resist any secondary deviating force as strongly as it resisted the first. We are not aware

whether the principle of the gyroscope has yet been adopted in steering fish torpedoes; if not it ought to be tried, as it promises well. It does not seem to us, indeed, that any impassable obtacle exists to the construction of a fish torpedo or submerged boat, which shall possess automatic steering power sufficient to preserve a line sufficiently straight to insure that the weapon shall strike so large a mark as a man-of-war at moderate range. All that can be said certainly on such a subject, however, is that the locomotive torpedo becomes day by day more manageable; and it is not impossible that naval officers will soon be placed in possession of tables of deviation for their guidance when using the torpedo in a current. These tables would show, for example, if a ship to be attacked lay north of another at a range of say two miles, how many points to the west the head of the torpedo must be laid to provide for the effects of a current flowing at a given velocity in an easterly direction.

THE CALCULATION OF EARTHWORK.

By N. B. PUTNAM, C. E.

Written for Van Nostrand's Engineering Magazine.

The author (Mr. Davis) of the article, "The Earthwork Question," which appeared in the December number of this Magazine, has found in Simpson's Rule so formidable an obstacle to a fair understanding of my paper of last October, that it does not appear out of place to preface the present article with a short discussion of Simpson's Rule and the Prismoidal Formula.

A Prismoid may be defined as a solid contained between two parallel planes and composed of prisms, wedges and pyramids, whose common altitude is the perpendicular distance between the parallel faces. The rule for the solidity of a prismoid was first demonstrated, in later days, by Thomas Simpson, an English mathematician of the last century, and may be given as follows:

Simpson's Rule.—To the sum of the areas of the two ends of a prismoid, add four times the area of a section made by a plane parallel to and equi-distant from both ends; multiply the result by the altitude, and one-sixth of the product will equal the solidity.

This rule, which has been variously stated, is now generaly known by the name of the *prismoidal formula*, which, expressed in algebraic language, is

$$V=\frac{l}{6}(S_1+4S_m+S_2), \qquad (A)$$

V being the volume and l the altitude of the prismoid, S_1, S_2 the end, and S_m the middle areas. By dividing (A) by a we get

$$\frac{V}{a}=\frac{l}{6}\cdot\frac{S_1+4S_m+S_2}{a}, \qquad (A')$$

which expresses the area of the base of the equivalent prism of altitude a. Now it is well known that some bodies which are not prismoids may have their volumes expressed by the prismoidal formula; thus the volume of the sphere

$$=\frac{4}{3}\pi p^3=\frac{2p}{6}(0+4\pi p^2+0)$$

the areas of the bases of their equivalent prisms will then be given by the expression (A'). If, therefore, we determine those figures whose areas are given by (A'), we may the more easily determine those solids whose volumes may be found by Simpson's Rule.

In (A') let

$$\frac{V}{a}=A,\ \frac{S_1}{a}=y_1,\ \frac{S_m}{a}=y_m,\ \frac{S_2}{a}=y_2,$$

then $$\frac{V}{a}=A=\frac{l}{6}(y_1+4y_m+y_2) \qquad (B);$$

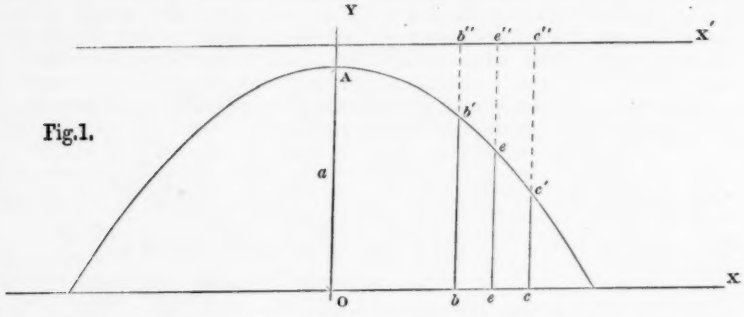
now if $y_m=\frac{1}{2}(y_1+y_2)$, A will represent the area of a rectangle, a triangle or a trapezoid. Therefore those solids which have these figures for the bases of their equivalent prisms of altitude a, may have their solidities determined by the prismoidal formula; in other words, if the areas of the sections of a solid made

by parallel planes be proportional to the ordinates of a right line the volume of the solid may be found by Simpson's Rule.

Among the solids of this class may be mentioned the prism, the rectangular wedge, and the paraboloid of revolution.

In (Fig. 1) let A be the vertex and o Y the axis of a parabola, and let o be the origin of co-ordinates; and let it be required to find the area $bb'c'c$ included

Fig. 1.



between the parabolic arc $b'ec'$, the axis of x and the two given ordinates bb', cc'. Put $oA=a$, $ob=x_1$, $bb'=y_1$, $oc=x_2$, $cc'=y_2$ $oe=x_m=\frac{x_1+x_2}{2}$ and $e\,e'=y_m$.

From the eq. to the parabola we have

$$x^2=2p\,(a-y), \text{ or } y=a-\frac{x^2}{2p} \quad . \quad . \quad (1)$$

the expression for the differential of the area is

$$d\,A=y\,dx=\left(a-\frac{x^2}{2p}\right)dx;$$

$$\therefore\ A=\int_{x_1}^{x_2}\left(a-\frac{x^2}{2p}\right)dx=\text{area } bb'cc',$$

$$A=\left(ax-\frac{x^3}{6p}\right)_{x_1}^{x_2}=ax_2-ax_1-\frac{x_2^3-x_1^3}{6p}$$

$$=\frac{x_2-x_1}{6}\left(6a-\frac{x_2^2+x_1^2}{p}-\frac{x_2\,x_1}{p}\right) \quad (2)$$

In equation (1) make $x=x_m$, then

$$y_m=a-\frac{x_m^2}{2p}=a-\frac{x_2^2+x_2\,x_1+x_1^2}{8p}$$

and $$4\,y_m=4\,a-\frac{x_2^2+x_1^2}{2p}-\frac{x_2\,x_1}{p}.$$

Introducing $4\,y_m$ into equation (2) gives

$$A=\frac{x_2-x_1}{6}\left(2a-\frac{x_2^2+2\,x_1^2}{2p}+4\,y_m\right);$$

or, since $a-\frac{x_2^2}{2p}=y_2$ and $a-\frac{x_1^2}{2p}=y_1$,

$$A=\frac{x_2-x_1}{6}(y_1+4\,y_m+y_2)=\text{area } bb'c'c \quad (3)$$

which is in the form (B).

This expression may also be used to determine the area $b''b'c'c''$, $b''X'$ being now the axis of x. If, therefore, the areas of the sections of a solid made by parallel planes be proportional to the ordinates of the parabola of Fig. 1, the volume of the solid may be determined by the prismoidal formula.

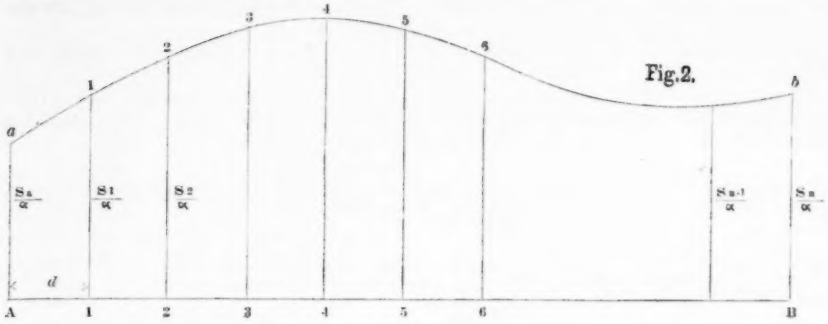
Among the solids of this class may be mentioned the double-edged wedge, the pyramid, the ellipsoid of revolution and certain warped solids.

Simpson's Rule, moreover, affords a convenient and very approximate method of finding the volume of an irregular solid, in which an odd number of equidistant and parallel sections are given. Let A B (Fig. 2) represent the length of such a solid and A a 1234....b B the base of the equivalent prism of altitude a; let the common distance between the sections be d. Consider any one pair of bands as 22344 into which the ordinates divide the base. The boundary line 234 may without material error be considered a parabolic arc; the area of this portion of the base may therefore be found by eq. (A′), and the corresponding volume by eq. (A). Beginning at A, we have

$$\text{Volume A } a\ 122=\frac{d}{3}\,(S_a+4\,S_1+S_2),$$

$$\text{“ } \quad 22344=\frac{d}{3}\,(S_2+4\,S_3+S_4),$$

$$\text{“ } \quad 44566=\frac{d}{3}\,(S_4+4\,S_5+S_6), \text{ &c.}$$



Adding we have for the volume

A a 12345.....b B

$$=V=\frac{d}{3}(S_a + 4S_1+2S_2+4S_3+ \ldots +4S_{n-1}+S_n) \quad (C)$$

This method, although more than a century old, is still the simplest and best at present known for approximating the area of irregular curves or the volume of irregular solids. It is to this "novel" method, when applied to the computation of earthwork, that Mr. Davis finds serious objection. He says: "The author is also led into the following great error: 'When the sections are equi-distant, the solidity of the excavation should be found by the prismoidal formula using measured middle areas; in other words, by the application of Simpson's Rule, substituting the cross-sectional areas for the length of the ordinates.'"

Since Mr. Davis objects to the use of the prismoidal formula, using measured, that is the actual middle areas, and at the same time kindly advise the author to cling to the prismoidal rule, it is difficult for one to determine whether he considers assumed middle areas more reliable than the actual ones, or has given to the formula a new and better application.

The following extract from Rankine's Civil Engineering, Art. 186, p. 329, requires no explanation: "CASE II. *When three equi-distant cross-sections,* S_0, S_1, S_2, *are given, with the total length* X, *of the piece of earthwork between them,* the best approximation is

$$V=x.\frac{S_0+4S_1+S_2}{6}."$$

In the method usually employed for estimating volumes of earth, each of the blocks, into which the cross-sections divide an excavation or embankment, is regarded as a right-lined solid; upon this assumption its middle area is determined by means of the dimensions of the end sections, and its volume found by the prismoidal formula. Since the assumed middle area is usually less than the arithmetical mean of the end areas, the volume found by this method of calculation is less than that found by averaging the end areas. We may say, therefore, that the sections of a block of earth are proportional to the ordinates of a curve convex towards the axis of abscissas.

Let Fig. 3 represent the longitudinal section of a piece of earthwork given by the areas of the cross-sections at 1, 2 and 3. The solid is thus divided into two blocks of earthwork. Let the cross-sectional areas be respectively proportional to 1_1, 2_2, 3_3 (Fig. 3A), *i. e.* let

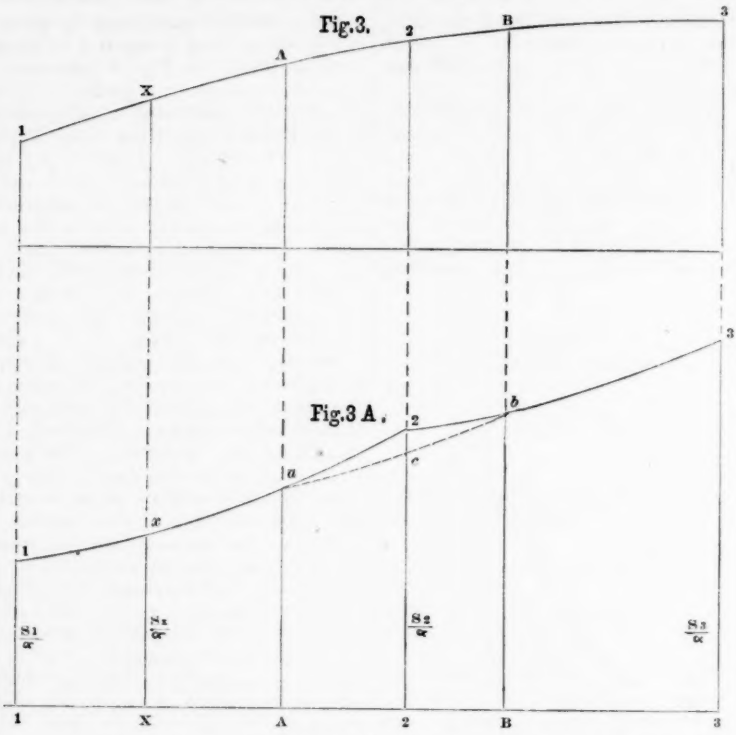
$$1_1=\frac{S_1}{a},\ 2_2=\frac{S_2}{a},\ 3_3=\frac{S_3}{a}.$$

Now, if the method usually employed be correct, these two blocks of earth are equivalent to a prism whose altitude is a, and whose base is $1_1\,a\,2\,b\,3_3\,3$. From this base the cross-sectional area at any point of the solid may be obtained; thus the cross-sectional area at X is

$$S_x = X_x \times a.$$

Consider now the solid contained between the cross-sectional planes at A and B; the area of the cross-section at A is, $S_a = A\,a \times a$, that at B is, $S_b = B\,b \times a$. If the volume of this block of earth, as determined by the "*Method of the Prismoidal Formula,*" be the true volume,

Fig.3.



this solid is equivalent to a prism whose altitude is a and whose base is A a c b B; as before, the area of any cross-section of the block may be found from the corresponding ordinate of this base. Thus $S_2 = 2c \times a$, but by construction $S_2 = 2_2 \times a$, whence $2c = 2_2$, which is absurd.

Whence we infer that the cross-sectional areas of a solid of earthwork are not proportional to the ordinates of the curve of Fig. 3A. We conclude, therefore, that a block of earthwork is not a prismoid, that the surface of the ground is not a surface of right-line generation, and that this method of calculation usually gives *less* than the true amount.

The failure of the "Prismoidal Method" to give true results, arises not from any inaccuracy of the prismoidal formula, which with the actual middle area will give the true volume, but is due to the erroneous assumption, that a block of earth is a right-lined solid. This fallacy is very apparent when we consider the forms of the longitudinal and cross-sections of a piece of earthwork; thus in the longitudinal section the surface line is always supposed to be straight, while in the cross-section, the surface line is generally broken into two right lines; yet the sum of the "distances out" is usually less than sixty feet, while the distance between the cross-sections, *i. e.* the length of the longitudinal section, is generally 100 feet.

The ground surface of a solid of earthwork is generally curved and always irregular; since the form of this surface is seldom if ever definitely known, the best and probably the only reliable approximation to the volume is obtained by regarding the piece of earthwork as an irregular solid. When such a solid is given by the areas of an odd number of equivalent cross-sections, the best approximation to the volume is given, as has already been stated, by a continued application of the prismoidal formula, using only measured areas. And there

now remains to be considered the case, of more frequent occurrence, in which the blocks of earth have different lengths.

If, in an excavation or embankment, we measure the areas of the cross-sections at every foot of the length, and construct the base of an equivalent prism, we shall find that the form of this base, although depending to some extent upon the character of the ground, is that represented in Fig. 4; the bounding

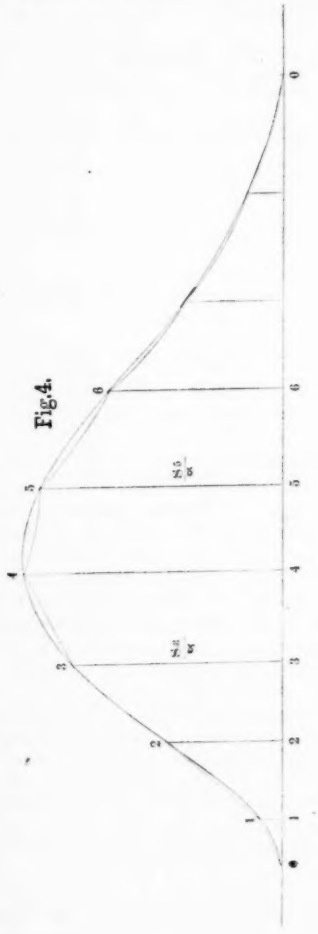


Fig. 4.

curve being convex downwards at the ends and concave downwards at the middle portion.

Let a piece of earthwork be given by the positions and areas of a number of cross-sections, let Fig. 4 represent the base of the equivalent prism of altitude a, and let the ordinates 1_1, 2_2, 3_3, &c., be proportional to the given cross-sectional areas. If now the volume of any block of the piece of earthwork be found by the mean areas' method of calculation, by joining the upper ends of the ordinates, corresponding to the given end areas, by a right line, we obtain the base of the prism whose altitude is a, and whose volume equals the estimated volume of the block. It is evident, therefore, that this method of calculation gives more than the true amount in the blocks of earth at the ends, and less than the true volume in the blocks at the middle of the earthwork. For a whole excavation or embankment the mean areas' method *seldom* gives *more* than the true volume. If the volume of a block be determined by the "*prismoidal method*," the base of the prism, of altitude a and of volume equal to the estimated volume, may be found by joining the ends of the ordinates, corresponding to the given end areas, by a curved line, convex downwards. This method of calculation, as is seen in the figure, usually gives *less* than the true volume of a block at the ends as well as at the middle of the earthwork; although at the ends it gives a close approximation to the true volume.

There is no method of calculation in present use which, at all times, gives even approximately, the contents of a solid of earth given only by its length and the areas of the end sections; and so long as the object of earthwork computation is to determine the volume of earth removed from an excavation or put into an embankment, there seems to be no reason why we should not deal directly with the solid in question in approximating the total volume, or why we should replace it by prismoids;—bodies which have no place in practical earthwork.

LARGE IRON PLATE.—Messrs Charles Cammell & Co., of the Cyclops Works, Sheffield, last year, rolled an armor plate 22 inches thick, 8 inches thicker than any armor plate ever before produced.

TRANSMISSION OF POWER BY WIRE ROPES.*

By ALBERT W. STAHL, M. E., Cadet-Engineer, U. S. N.

II.

Section V.

THE CATENARY.

If a rope or other flexible continuous line be secured at two points and loaded continuously between them according to any law, it will assume some definite curvilinear form. When the load is the weight of the rope only, the curve is called a "catenary."

Suppose that the rope is fixed at the points A and B (see Fig. 16), and that

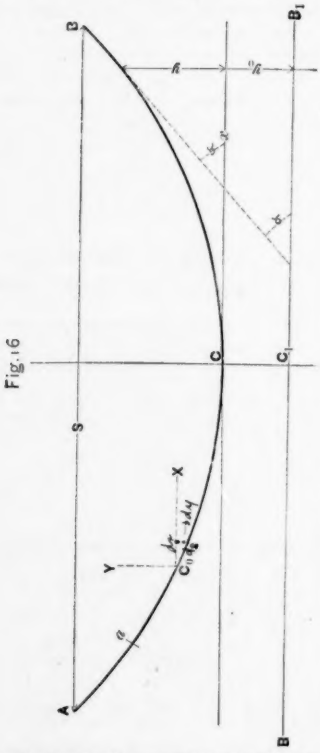


Fig. 16

the only force in operation is the weight of the rope, *i. e.* the load is a continuous and direct function of the length of arc. Take the origin of co-ordinates at any point on the curve (C_0), the axis of Y being vertical and the axis of X horizontal. All our forces being in one plane, the axis of Z is of course unnecessary.

Let t' = tension at any point, as a.

t_0 = tension at the origin C_0.

X_0 = horizontal component of the tension at $C_0 = t_0 \frac{dx'}{ds}$

Y_0 = vertical component of the tension at $C_0 = t_0 \frac{dy'}{ds}$

X = horizontal component of applied forces between C_0 and a.

$\frac{dx}{ds}, \frac{dy}{ds}$, will be the cosines of the angles which the curve makes with its respective axes, and resolving t' we have

$t'\frac{dx}{ds}$ = horizontal component of tension,

$t'\frac{dy}{ds}$ = vertical component of tension,

Consequently, from the principles of Mechanics, we must have, for equilibrium

$$\left.\begin{aligned} X + X_0 + t'\frac{dx}{ds} &= 0 \\ Y + Y_0 + t'\frac{dy}{ds} &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad (18)$$

These equations are perfectly general for any case in which the applied forces are in one plane.

To get a more definite result for the case under consideration, we will take the origin at the lowest point C and the axis of X tangent to the curve at that point; this will make $\frac{dx'}{ds} = 1$ and $\frac{dy'}{ds} = 0$; as the weight acts vertically, $X = 0$. With these substitutions we get

$$\left.\begin{aligned} t'\frac{dx}{ds} + t_0 &= 0 \\ Y + t'\frac{dy}{ds} &= 0 \end{aligned}\right\} \quad . \quad . \quad . \quad (19)$$

Let w = weight per running foot of rope,

* A graduating thesis at the Stevens Institute of Technology, Hoboken, N. J., June 30th, 1876.

and s=length of curve in feet; then ws= weight of the rope; and as this is the only vertical force we have $ws=Y$.

This reduces the above equations to the following:

$$\left.\begin{aligned} t'\frac{dx}{ds}&=t_0\\ t'\frac{dy}{ds}&=ws\end{aligned}\right\} \quad . \quad . \quad . \quad (20)$$

Equation (20) shows that the horizontal component of the tension is equal to the tension at the lowest point, *i. e.*, the horizontal component of the tension is constant throughout the curve. We also observe that the vertical component of the tension at any point is equal to the weight of so much of the rope as comes between the origin and the point considered.

Dividing the first of equations (20) by the second, we get

$$\frac{dx}{dy}=\frac{t_0}{ws} \quad . \quad . \quad . \quad (21)$$

which shows that the tangent of the angle varies inversely as the weight of the rope.

Differentiating equation (21) we have $d\left(\frac{dy}{dx}\right)=\frac{w}{t_0}ds$, but $ds=(dx^2+dy^2)^{\frac{1}{2}}=\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}dx$. Substituting this value, we have, after transposing

$$\frac{w}{t_0}dx=\frac{d\left(\frac{dy}{dx}\right)}{\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}} \quad . \quad . \quad . \quad (22)$$

Integrating equation (22), we obtain

$$\frac{w}{t_0}x=\text{Nap. log.}\left(\frac{dy}{dx}+\sqrt{1+\frac{dy^2}{dx^2}}\right)$$

This may be written $e^{\frac{wx}{t_0}}=\frac{dy}{dx}+\sqrt{1+\frac{dy^2}{dx^2}}$; transposing, we get

$$e^{\frac{wx}{t_0}}-\frac{dy}{dx}=\left(1+\frac{dy^2}{dx^2}\right)^{\frac{1}{2}}$$

Squaring this equation we get

$$e^{\frac{2wx}{t_0}}-2e^{\frac{wx}{t_0}}\frac{dy}{dx}+\frac{dy^2}{dx^2}=1+\frac{dy^2}{dx^2} \quad . \quad . \quad (23)$$

Reducing and clearing of fractions, we get

$$dy=\tfrac{1}{2}\left\{e^{\frac{wx}{t_0}}-e^{\frac{-wx}{t_0}}\right\}dx \quad . \quad (24)$$

Integrating the above equation, we obtain

$$y=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\}+\left\{C=-\frac{t_0}{w}\right\}$$

$$\therefore\ y+\frac{t_0}{w}=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\} \quad . \quad (25)$$

which is the equation of the catenary. To bring this equation into a simpler and more manageable form, we will transfer the origin of coordinates to C_1, making $CC_1=\frac{t_0}{w}$. Then our new ordinates will be equal to $y+\frac{t_0}{w}$, so that the last equation may be written

$$y_0=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}+e^{\frac{-wx}{t_0}}\right\} \quad . \quad . \quad . \quad (26)$$

But in making this change of origin, $\frac{dy}{dx}$, the tangent of the angle α evidently remains constant, and having previously found $\frac{dy}{dx}=\frac{ws}{t_0}$, we will substitute this value in equation (24), giving rise to the following value for the length of arc:

$$S=\frac{t_0}{2w}\left\{e^{\frac{wx}{t_0}}-e^{\frac{-wx}{t_0}}\right\} \quad . \quad (27)$$

Squaring equations (26) and (27), we get

$$y_0^2=\frac{t_0^2}{4w^2}\left\{e^{\frac{2wx}{t_0}}+2+e^{\frac{-2wx}{t_0}}\right\} \quad . \quad (26a)$$

$$S^2=\frac{t_0^2}{4w^2}\left\{e^{\frac{2wx}{t_0}}-2+e^{\frac{-2wx}{t_0}}\right\} \quad . \quad (27a)$$

Subtracting ($27a$) from ($26a$), we have

$$y_0^2-S^2=\frac{t_0^2}{w^2}$$

$$S=\sqrt{y_0^2-\frac{t_0^2}{w^2}} \quad . \quad . \quad . \quad (28)$$

Equation (28) gives us the length of arc when the running weight of the rope, and the ratio $\frac{t_0}{w}$, are known. The weight of the rope is always known in any given case.

To find the value of $\frac{t_0}{w}$, we proceed as follows:

Let Δ = total deflection or greatest ordinate of the curve.

S = span between supports.

Then, for the lowest point, the ordinate is $y_0 = \Delta + \frac{t_0}{w}$; and the abscissa $x = \frac{1}{2}$ S. Substituting these values in equation (26) and reducing, we get

$$\frac{t_0}{w} = \frac{2\Delta}{e^{\frac{w\,S}{2t_0}} + e^{\frac{-w\,S}{2t_0}} - 2} \quad . \quad . \quad . \quad (29)$$

The equation just found is not susceptible of a direct solution; so that it becomes necessary to find the value of $\frac{t_0}{w}$ by a method of approximation. This will be done in the next section (VI).

Let L = total length of rope between supports; then from equation (28),

$$L = 2\sqrt{\left(\Delta + \frac{t_0}{w}\right)^2 - \frac{t_0^2}{w^2}} = 2\sqrt{\Delta^2 + \frac{2\Delta t_0}{w}} \quad (30)$$

To find the tension at any point, we know that from the parallelogram of forces

$$t'^2 = \left(t'\frac{dy}{ds}\right)^2 + \left(t'\frac{dx}{ds}\right)^2.$$

We substitute in this equation the values obtained from equation (20), and get

$$t'^2 = w^2 s^2 + t_0^2 = w^2\left(y_0^2 - \frac{t_0^2}{w^2}\right) + t_0^2 = w^2 y_0^2$$

$$t' = w y_0 \quad . \quad . \quad . \quad . \quad . \quad (31)$$

The tension t' is a maximum at the highest points. The ordinates for these points being $\Delta + \frac{t_0}{w}$, we have

$$t' = w\left(\Delta + \frac{t_0}{w}\right) = w\Delta + t_0 \quad . \quad . \quad (32)$$

The vertical component of the tension at the highest point is, of course,

$$ws = w\sqrt{y_0^2 - \frac{t_0^2}{w^2}} = \sqrt{w^2 y_0^2 - t_0^2} \quad . \quad (33)$$

The tangent of the angle α, which the curve, at the highest point, makes with the axis of X, is $\tan \alpha = \frac{ws}{t_0} = \frac{wL}{2t_0} = \frac{w}{t_0}\left(\Delta^2 + \frac{2\Delta t_0}{w}\right)^{\frac{1}{2}} = \left(\frac{w^2\Delta^2}{t_0^2} + \frac{2w\Delta}{t_0}\right)^{\frac{1}{2}}$ . . . (34)

We have now developed all the necessary equations of the catenary; but before applying them, a few remarks on the peculiarities of the curve, as shown by its equations, may not be out of place.

Equation (26) shows that the catenary rises symmetrically on both sides of the axis of Y, and becomes parallel to the same only at an infinite distance.

The angle α increases with the ordinate y; when y becomes infinite, $\alpha = 90°$; when $y = o$, $\alpha = o$.

The line CC, $\left(= \frac{t_0}{w}\right)$ is called the parameter of the curve; and the line BB., last used as the axis of abscissas, is called the directrix.

The value of the ratio $\frac{t_0}{w}$ varies between zero and infinity, $\frac{t_0}{w} = o$ when $\Delta = \infty$; for in this case the two exponents in equation (26) also become zero; $\frac{t_0}{w} = \infty$, when $\Delta = o$, because the two exponents there each equal unity. The value of $\frac{t_0}{w}$ is always very large, when Δ is small, as it always is in transmitting power by wire rope.

As will be seen from equations (31) and (32), the tension in the rope is directly proportional to the weight of the latter. The tension reaches its maximum at A and B, and has its minimum at C, where $t' = t_0$.

When Δ is small, there is very little difference between t_0 and t'; and as $\frac{t_0}{w}$ is always very large, the results obtained from equations (29) and (31) will not differ greatly.

The tension $t' = t_0 = \infty$, when $\Delta = o$; this shows the impossibility of stretching a rope so as to be perfectly horizontal; because even when it is hauled as taut as

may be, there must always be a finite value of Δ existing.

Section VI.

APPROXIMATE SOLUTION OF CATENARY.

In practically applying the preceding equations of the catenary, we meet with considerable difficulty, which is owing to the fact that the parameter $\frac{t_0}{w}$ can only be obtained from a transcendental equation.

But in such work as forms the subject of this thesis, we can pursue a frequently-used method of approximation, which is abundantly accurate for all our purposes. The exact equations of the catenary, as we have deduced them, are of course applicable; but, as we have left the stiffness of the rope out of consideration, and assumed it to be "perfectly flexible," the shape of the curve is not expressed with mathematical exactitude by even these equations. For this reason alone, it might be permissible to use approximate formulæ; but we have a still greater right to use them, because the deflection Δ is always a very small fraction of the span S, and, therefore, the parameter $\frac{t_0}{w}$ is always very large.

Consequently, in equation (29), the exponent $\frac{wS}{2t_0}$ is a small fraction; and we can, without committing any great error, express its value by the series

$$e^{\frac{wS}{2t_0}} = 1 + \frac{wS}{2t_0} + \frac{w^2S^2}{2\times 4t_0} + 2\frac{w^3S^3}{2\times 3\times 8\,t_0^3} +$$

$$e^{-\frac{wS}{2t_0}} = 1 - \frac{wS}{2t_0} + \frac{w^2S^2}{2\times 4t_0} - \frac{w^3S^3}{2\times 3\times 8\,t_0^3} +$$

Taking the first four terms of these series, and substituting them in equation (29), we get

$$\frac{t_0}{w} = \frac{2\Delta}{2 + \frac{w^2S^2}{4t_0^2} - 2} = \frac{2\Delta}{\frac{w^2S^2}{4t_0^2}} = \frac{S^2}{8\Delta} \quad . \quad (35)$$

Substituting the same terms of a similar series in equation (26), we get

$$y_0 = \frac{t_0}{2w}\left(2 + \frac{w^2x^2}{2t_0^2}\right) = \frac{t_0}{w} + \frac{wx^2}{4t_0}$$

$$y_0 - \frac{t_0}{w} = \frac{wx^2}{4t_0}$$

$$y_0 - \frac{S^2}{8\Delta} = \frac{wx^2}{4t_0} \quad . \quad . \quad . \quad . \quad . \quad (36)$$

This is the equation of a parabola having a parameter of $\frac{S^2}{4\Delta}$; so that our method of approximation has led us to consider the curve as a parabola.

Substituting the value $\frac{t_0}{w} = \frac{S^2}{8\Delta}$ in equation (30), we get for the length of the curve between supports

$$L = 2\sqrt{\Delta^2 + \frac{2\Delta S^2}{8\Delta}} = 2\sqrt{\Delta^2 + \frac{S^2}{4}} \quad . \quad (37)$$

By reference to the figure, it will be seen that this is equivalent to assuming that the length of the curve is equal to twice the length of the chord of half the curve. All the formulæ previously found now become, by the proper substitutions

$$t' = w\left(\Delta + \frac{S^2}{8\Delta}\right) \quad . \quad . \quad . \quad . \quad (38)$$

$$t_0 = \frac{wS^2}{8\Delta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

$$t'\frac{dy}{dx} = w\left(\Delta^2 + \frac{S^2}{4}\right)^{\frac{1}{2}} \quad . \quad . \quad . \quad (40)$$

$$\tan.\, a = \frac{8\Delta}{S^2}\left(\Delta^2 + \frac{S^2}{4}\right)^{\frac{1}{2}} \quad . \quad . \quad . \quad (41)$$

By means of these formulæ, it becomes an easy matter to investigate the various problems which present themselves.

Section VII.

DEFLECTION OF THE ROPE.

In order that the rope may be subjected to a proper tension, the deflection or sag must be of a certain magnitude while the rope is at rest; we must also know the sag of the rope while in motion, in order to estimate the necessary elevation of the wheels. There are therefore three deflections which we must determine: 1st, that of the driving side while in motion; 2nd, that of the following side wheel in motion; 3rd, that of both sides when the rope is at rest. Let the deflection at rest be called Δ_0. When we start one of wheels, the driving side of the rope rises and the following side is depressed, until the difference of their tensions is equal to the force to be transmitted, when the driven wheel will begin to move; in this con-

dition we will call the deflection of the driving side Δ_1 and that of the following side Δ_2.

We must know the deflection at rest, Δ_0, in order to determine the proper length of rope; so that when it is put on and spliced, we may feel certain, that there will be neither any slipping during the motion, nor any serious strain on the rope itself. The deflections Δ_1 and Δ_2, as before stated, must be known, in order to determine in advance, what position the ropes will take while in motion, how near they will approach the ground or other obstructions, and how many, if any, carrying sheaves are required.

By solving equation (38) for Δ, we get for the value of the deflection

$$\Delta = \frac{t'}{2w} - \sqrt{\left(\frac{t'}{2w}\right)^2 - \frac{S^2}{8}} \quad . \quad . \quad (42)$$

Now, we have seen in Section IV, that if the force at the circumference of the wheel is P, then to find the deflection Δ_1 of the driving side, $t' = 2P$. To find the deflection Δ_2 of the following side, $t' = P$. Lastly, to find the deflections Δ_0 of both sides while at rest $t' = \frac{3}{4}P$.

In applying equation (42) and all other equations containing t', it is to be borne in mind that t' is not the tension per square inch, but is the whole tension on the rope.

From this equation, it is evident that the tension has a great influence on the deflection of the rope. This is best shown by an example. Suppose that, with a span of 400 feet, we are using a $1\frac{1}{8}$ inch rope working under a tension of 3,000 pounds. By making the proper substitutions in equation (42) we get

$$\Delta = \frac{3000}{1.20} - \sqrt{\left(\frac{3000}{1.20}\right)^2 - \frac{(400)^2}{8}} = 2 \text{ feet.}$$

Now if we had the same rope working under a tension of only 2,400 pounds, the deflection would be

$$\Delta = \frac{2400}{1.20} - \sqrt{\left(\frac{2400}{1.20}\right)^2 - \frac{(400)^2}{8}} = 5 \text{ feet.}$$

Thus, a difference in tension of only 600 pounds, causes a difference in deflection of three feet.

In both these cases, the rope will work equally well, if the size of the wheel has been properly selected; but in most cases, it is not a matter of indifference whether the rope has a deflection of two feet or of five feet.

The smaller deflection is usually to be preferred, as it requires a less elevation for the wheels. On the other hand, with a very short span the greater deflection is generally preferable.

It is, therefore, evident that we cannot decide on any definite tension to be used in all cases, but that we must select it for every different case, using a greater tension as we want a less deflection, and *vice versa*.

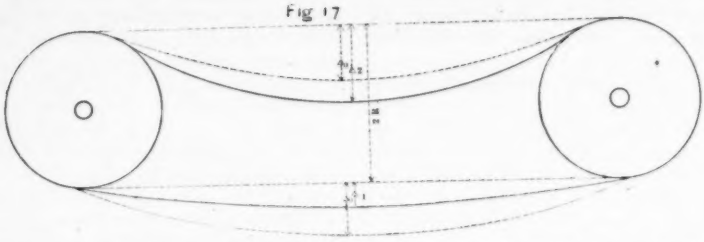
But in order that the rope may work equally well in any case, we must, as previously explained, keep the *sum* of the various tensions constant, *i. e.*, equal to the ultimate strength of the rope divided by the factor of safety. By a proper adjustment of the tension, we can, in nearly all cases, bring the deflection to any desired amount; but there is still another way to accomplish this end, as follows:

Generally, we are not compelled to make the upper side of the driving rope act as the driving side, but we can often use the lower side for this purpose. In that case the greater deflection of the lower side takes place while the rope is at rest (See Fig. 17). When in motion, the lower side rises above this position, and the upper side sinks, thus enabling us to avoid obstructions, which, by the other way would have to be removed. Of course this expedient cannot always be employed, as the upper side of the rope must not be allowed to sink so far as to pass below or even to touch the lower side. If this occurs, the rope begins to sway and jerk in a serious manner, wearing out very rapidly.

The shortest distance between the ropes is $2R - (\Delta_1 - \Delta_0) - (\Delta_0 - \Delta_2) = 2R - (\Delta_1 \Delta_2)$. We must, therefore, always be careful, in using this plan, to see that $2R > \Delta_1 - \Delta_2$. This result may often be obtained by a judicious selection of the tension, and of the diameter of wheel.

By the application of the equations given in this and the preceding sections, we may solve all the problems which present themselves in designing a wire-rope transmission. The following table which is taken from Mr. W. A. Roebling's pamphlet, previously referred to, will be

Fig 17



found of great value in designing, giving as it does, the most suitable proportion for general use. Its use is self-evident; and it need only be remarked, that where there is a choice between a small wheel with fast speed, and a larger wheel with slower speed, it is usually preferable to take the larger wheel.

TABLE OF TRANSMISSION OF POWER BY WIRE-ROPES.

Diameter of Wheel in Feet.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.	Diameter of Wheel in Feet.	Number of Revolutions.	Trade No. of Rope.	Diameter of Rope.	Horse Power.
4	80	23	$\frac{3}{8}$	3.3	11	80	19	$\frac{5}{8}$ $\frac{17}{16}$	64.9
4	100	23	$\frac{3}{8}$	4.1			18		75.5
4	120	23	$\frac{3}{8}$	5.	11	100	19	$\frac{5}{8}$ $\frac{11}{16}$	81.1
4	140	23	$\frac{3}{8}$	5.8			18		94.4
5	80	22	$\frac{7}{16}$	6.9	11	120	19	$\frac{5}{8}$ $\frac{11}{16}$	97.3
5	100	22	$\frac{7}{16}$	8.6			18		113.3
5	120	22	$\frac{7}{16}$	10.3	11	140	19	$\frac{5}{8}$ $\frac{11}{16}$	113.6
5	140	22	$\frac{7}{16}$	12.1			18		132.1
6	80	21	$\frac{15}{32}$	10.7	12	80	18	$\frac{11}{16}$ $\frac{3}{4}$	93.4
6	100	21	$\frac{15}{32}$	13.4			17		99.3
6	120	21	$\frac{15}{32}$	16.1	12	100	18	$\frac{11}{16}$ $\frac{3}{4}$	116.7
6	140	21	$\frac{15}{32}$	18.7			17		124.1
7	80	20	$\frac{1}{2}$	16.9	12	120	18	$\frac{11}{16}$ $\frac{3}{4}$	140.1
7	100	20	$\frac{1}{2}$	21.1			17		148.9
7	120	20	$\frac{1}{2}$	25.3	12	140	18	$\frac{11}{16}$ $\frac{3}{4}$	163.5
7	140	20	$\frac{1}{2}$	29 6			17		173.7
8	80	19	$\frac{9}{16}$	22.	13	80	18	$\frac{11}{16}$ $\frac{3}{4}$	112.
8	100	19	$\frac{9}{16}$	27.5			17		122.6
8	120	19	$\frac{9}{16}$	33.	13	100	18	$\frac{11}{16}$ $\frac{3}{4}$	140.
8	140	19	$\frac{9}{16}$	38.5			17		153.1
9	80	20		40.	13	120	18	$\frac{11}{16}$ $\frac{3}{4}$	168.
		19	$\frac{1}{2}$ $\frac{5}{8}$	41.5			17		183.9
9	100	20		50.	14	80	17	$\frac{3}{4}$ $\frac{7}{8}$	148.
		19	$\frac{1}{2}$ $\frac{5}{8}$	51.9			16		141.
9	120	20		60.	14	100	17	$\frac{3}{4}$ $\frac{7}{8}$	185.
		19	$\frac{1}{2}$ $\frac{5}{8}$	62.2			16		176.
9	140	20		70.	14	120	17	$\frac{3}{4}$ $\frac{7}{8}$	222.
		19	$\frac{1}{2}$ $\frac{5}{8}$	72.6			16		211.
10	80	19		55.	15	80	17	$\frac{3}{4}$ $\frac{7}{8}$	217.
		18	$\frac{5}{8}$ $\frac{11}{16}$	58.4			16		217.
10	100	19		68.7	15	100	17	$\frac{3}{4}$ $\frac{7}{8}$	259.
		18	$\frac{5}{8}$ $\frac{11}{16}$	73.			16		259.
10	120	19		82.5	15	120	17	$\frac{3}{4}$ $\frac{7}{8}$	300.
		18	$\frac{5}{8}$ $\frac{11}{16}$	87.6			16		300.
10	140	19		96.2					
		18	$\frac{5}{8}$ $\frac{11}{16}$	102.2					

SECTION VIII.

LIMITS OF SPAN.

It becomes interesting to know between what limits the span may vary, without giving impracticable results.

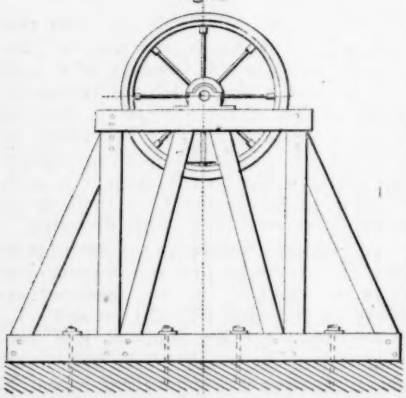
The least practicable span is that in which the deflection of the rope becomes so small, that the latter cannot be hung freely on the driving wheels, so that special tightening devices must be used. As such may be mentioned tightening

sheaves and moveable pillow-blocks. Of course it cannot be claimed that such devices make the transmission too complicated, but this merely changes the investigation for the lower limit of the span into one for the limit at which such special devices become necessary. To find the minimum value of the span we proceed as follows: From equation (38) we get an expression for the span in terms of t', w and Δ.

$$S = \sqrt{8\,\Delta\left(\frac{t'}{w} - \Delta\right)} \quad \ldots \quad (43)$$

By placing the minimum allowable values of Δ and $\frac{t'}{w}$ in this equation, we will get an expression for the smallest value of S. We will therefore assume that the deflection shall never be less than 8 inches $= \frac{2}{3}$ foot, and that the ratio $\frac{t'}{w}$ shall never go below 500. Introducing these values we get $S = \sqrt{8 \times \frac{2}{3}\,(500 - \frac{2}{3})} = 51.6$ feet. We thus see that the limit is very low, allowing us to use a free transmission for so short a distance as 51 feet. Below this, shafting will usually be found preferable and less troublesome.

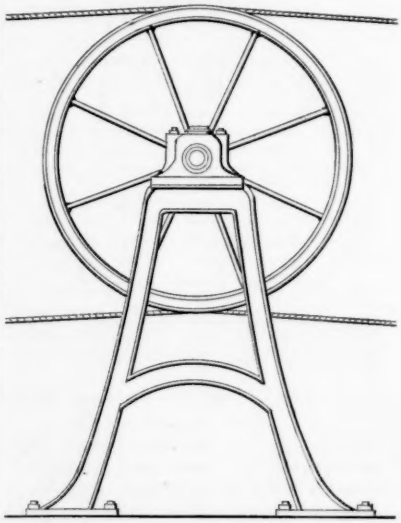
Fig. 18



When the distance of transmission materially exceeds three or four hundred feet, or when there is not sufficient height available for the sag of the rope, the latter must be supported at intermediate points by *carrying sheaves*. Sometimes it is sufficient to support only the lower following side of the rope, and generally, whatever the number of sheaves, the driving side is supported at one less point than the following side. The same number of sheaves may, however, be used, placing one over the other. The sheaves must never be placed side by side, as has been sometimes done to the great detriment of the transmission. To save still more room, we may, where practicable, make the lower rope the driving side, as previously explained.

The manner of arranging carrying sheaves and intermediate stations is shown in Figures 18–29 inclusive. The

Fig. 19



sheaves supporting the driving side of the rope must in all cases be of equal diameter with the driving wheels; and this for the same reason that the latter are usually made of so large a diameter. For whether the rope laps half way round on the driving wheels, or only quarter way round on the carrying sheaves, makes no difference; the tension due to bending is the same in both cases. With the following side, however, a somewhat smaller wheel may be used, owing to the fact there is less strain on this side, and it is therefore better able to stand the additional tension due to bending.

The system of carrying sheaves may generally be replaced by that of intermediate stations. When this is used, we have at each station, instead of two car-

Fig. 20

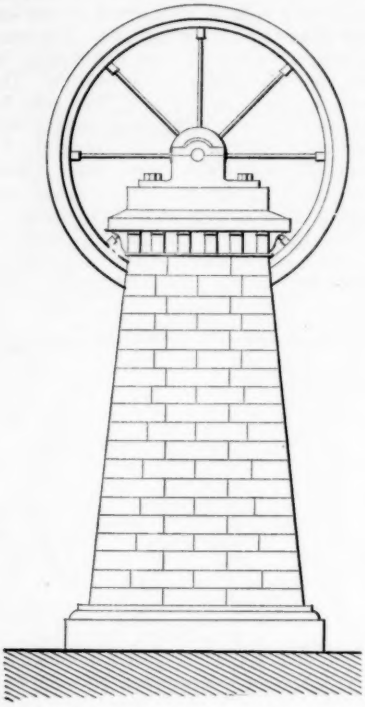
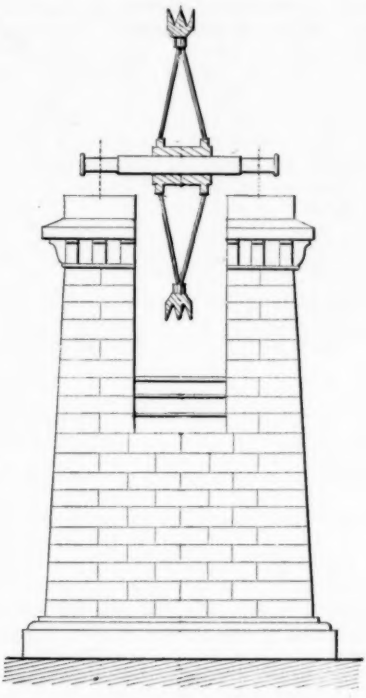


Fig. 21



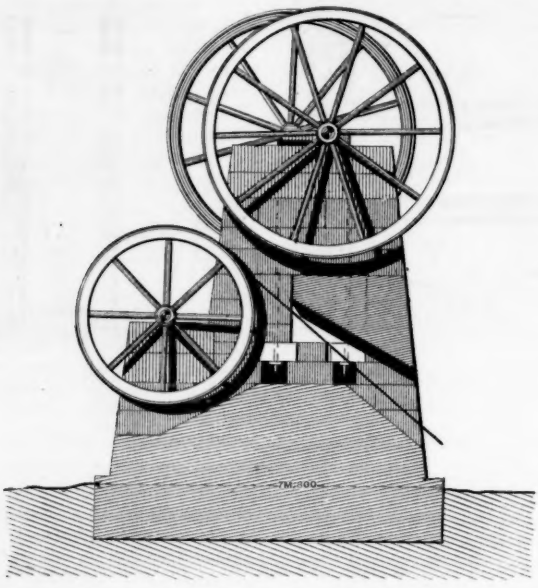
rying sheaves, one double grooved wheel. The rope, instead of running the whole length of the transmission, runs only from one station to the other. It is advisable to make the stations equidistant, so that a rope may be kept on hand, ready spliced, to put on the wheels of any span, should its rope give out. This method is greatly to be preferred where there is sometimes a jerking motion to the rope, as it prevents the rope from transmitting any sudden movements of this kind.

The supports for the stations are various. They range in dimensions and style from the simple wooden frame shown in Fig. 18, and the iron one of Fig. 19, to the more ornamental form of masonry (Figs. 20 and 21), and then to such immense masses of masonry as are shown in Figures 22–29. In Europe, the supports are usually built of masonry, while in this, wood is chiefly used, being bolted to a masonry foundation below the reach of frost. (In connection with Figures 20 and 21, I may say that the wheel there shown is one that is just coming into use. It consists of a cast iron hub and a rim, which are united by eight tension rods.) When a wooden frame is made to support the wheel, it must be firmly braced side-ways, to keep the wheel in the proper plane, but end-bracing is not required, as there is no tendency to push it in either direction.

To find the pressure on the bearings of one of the double-grooved wheels, the simplest method is by construction. Make A B= and ∥ T, B C,= and ∥ T., C D= and ∥ t, D E= and ∥ t_1, E F vertical and = the weight of the pulley and shaft, then the line connecting A and E is the intensity and direction of the resulting pressure. (See Figures 30 and 31.) When the rope is put on the wheels, it is best to use an arrangement similar to that shown in Figures 32 and 33. It is bolted to the rim of the wheel as shown.

If it is required to change the direction of the rope at some station, it can

Fig. 22



be done by the interpolation of horizontal sheaves, or by connecting the vertical driving wheels by bevel-gear. The latter is more usually employed. (See Figures 34 and 35.)

Fig. 23

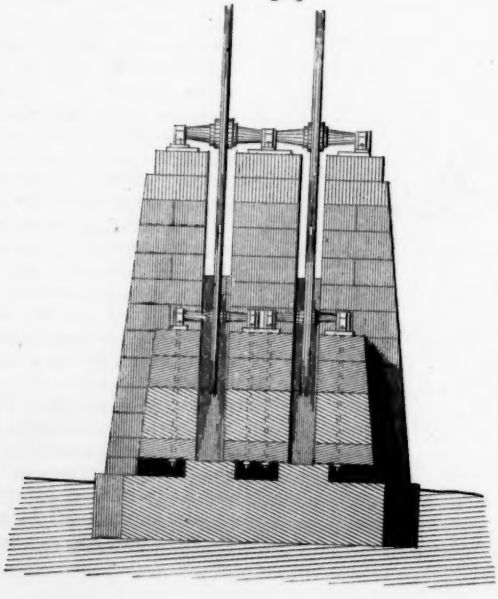


Fig. 24

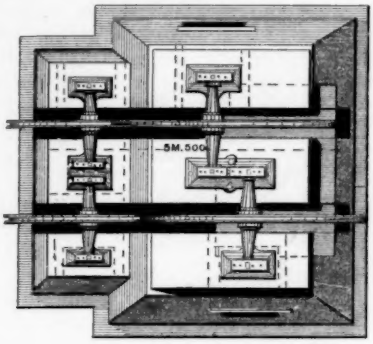
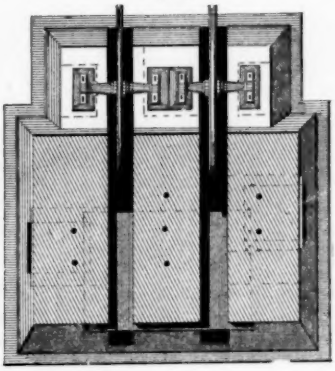


Fig. 25



Carrying Sheaves (3,150 Horse-Power).
Compagnie Générales de Bellegarde.

Section IX.

SPECIAL CASES.

It sometimes happens, that the two wheels are not at the same height, as has been hitherto supposed, but that one is at a higher level than the other. This frequently happens where it is desired to use the power of waterfalls in a ravine, or in conducting power up or down the side of a hill. The rope then takes a position similar to that shown in Fig. 36.

If the difference in height is slight, we can make use of the formulæ already found, without any serious error. But if it is great, we must take a different way, for in this case the tensions at the points of support are not the same, the lower one having a less tension than the one above. This somewhat complicates the problem, causing us to proceed as follows: We first make all the calculations for the lower wheel with the deflection $\triangle_1$ and the span $2S_1$; we then find the tension in the rope at the upper wheel, and proportion the diameter of the latter according to rules previously given, so that the total tension shall not exceed the ultimate strength divided by the factor of safety. To do this we must first determine S_1; this can easily be done from the property of the parabola that

$$S_1 = S \frac{\sqrt{\triangle_1}}{\sqrt{\triangle_1} + \sqrt{\triangle_2}}$$

when S = horizontal distance between the points of support.

The quickest and most usually employed method of getting the value of S_1 is the following. An accurate scale-drawing is made of the plan in which the rope is to be placed.

This drawing is set vertically, and a fine chain is fastened or held with its two ends at the points of support, until a proper deflection is obtained. It then becomes a matter of ease to measure S_1 and S_2, and to make all the necessary calculations. We can, in this way, try differne deflections and observe their suitability to the design, but must always bear in mind, whether we are getting the deflection of the driving or of the following side or that of both sides at rest. This method, though not giving as great accuracy as the solution of the above equation, is nevertheless largely used in practice, owing to its great convenience. It may be used when the pulleys are on the same level, showing between what limits we can work.

Another peculiar case is when the rope rises nearly in a vertical direction. This is the limiting case of the inclined transmission. The rope produces no tension whatever on the lower wheel, while at the upper wheel the tension is only equal to the weight of the rope. Even this last tension is such a small quantity as to be left entirely out of consideration, and we are consequently obliged to use some device for producing the requisite tension. Figures 37, 38 and 39 show various ways of accomplishing this object by means of tightening sheaves.

Fig. 26

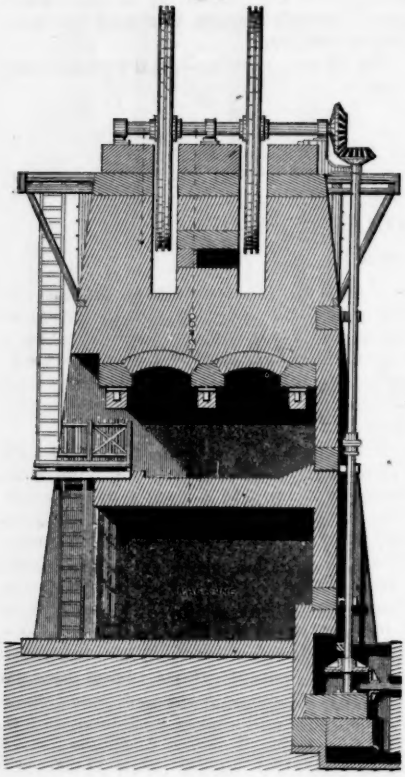


Fig. 27

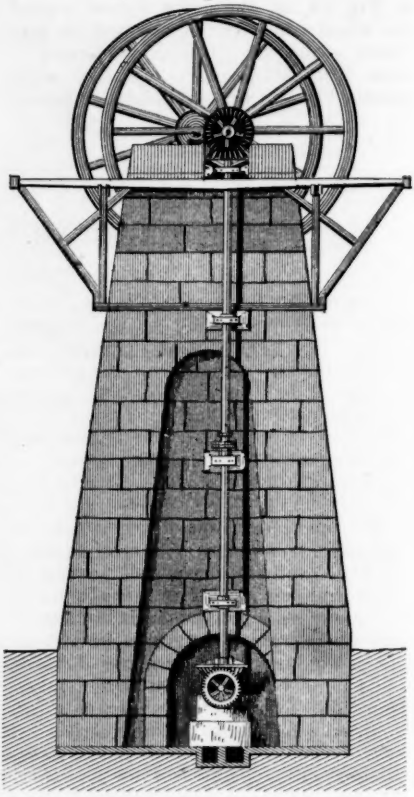


Fig. 28

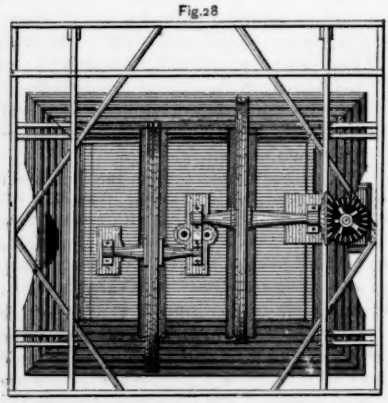
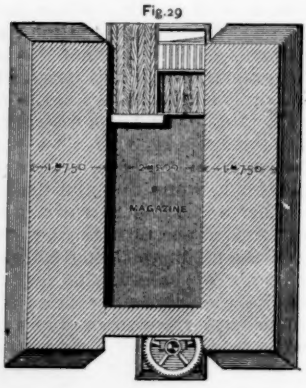


Fig. 29



Intermediate Station (3,150 Horse-Power).
Compagnie Générales de Bellegarde.
(See *Engineer*, vol. 37, 1834,)

In Fig. 38, as the rope passes around the wheel twice, the same must be provided with two grooves. Instead of these tightening sheaves, we may, when practicable, put up two carrying sheaves as shown in Fig. 39, so as to have horizontal stretch enough to obtain the tension necessary.

See March number for the remaining cuts.

ENGINEERING WORKS IN INDIA.

From "The Builder."

One of the features which have most struck the imagination of the English public, and, which have, perhaps, increased the disinclination at first naturally existing for the investment of capital in a distant and strange country, is the magnitude of the public works attempted and carried out in India. No doubt, individual works of great magnitude may be cited. The annicut across the Sone is two and a-half miles long in an unbroken line. The two main canals starting from this point are each 150 yards broad, and ten feet deep. The bund of the Veranum tank in South Arcot is twelve miles long, and about twenty ft. high. The tank itself is 2¼ miles wide in the widest part, and it will contain about one hundred million cubic yards of water. The highest bund which Sir Arthur Cotton has seen was fifty-four feet high, although he believes that there is a tank with a depth of sixty feet of water.

Noble as these works unquestionably are, it is rather in distribution than in gross magnitude of work that the labors of the engineer in India differ from those of his professional brother in England. We can point to no railway embankment of twelve miles long, but it would be only a very small railway that did not contain twelve miles of embankment distributed in various portions of its course. In the works at the head of river deltas, as in the case of the Cauvery, or in those for collecting water in the hills, as in the instance of the Veranum tank, a vast amount of work, intended to affect many hundred miles of country, is concentrated. The physical nature of the country demands this kind of work. But the details are as simple, and the cost is not much more, than that of the same quantity of work distributed over a larger area of country. Nor can either the cost or the magnitude of these great embankments and dams compare, in a disadvantageous manner, with that of such familiar undertakings as the bridging the Menai Straits, or the tunneling under the streets of London.

The simplicity with which works of permanent stability have long been constructed in India is a feature of their engineering to which we shall do well to pay attention. Extending over a great range of country, and formed out of every kink of material, the bunds are made without any such contrivance as a "puddle trench," which Sir Arthur Cotton regards as essentially mischievous, tending to lead to cracks in the mass of the bank. The great point is to have the embankments made of homogeneous material, so as to allow them to settle equally. Great watchfulness is also requisite, in the wet season, to prevent any overflow, except through the properly arranged sluices. The bursts of rain in the Carnatic are tremendous. As much as five inches of rainfall in a single night is not unfrequent, and Sir A. Cotton has known as much as twelve inches of rain to fall in that time. The smallest rill that is allowed to trickle over the edge of an earthen bank wears itself a passage, and becomes a destructive torrent with extreme rapidity. On one occasion the water in the Veranum tank is said to have overflowed the whole twelve miles of the bund, and to have breached it in thirteen places. On another occasion the engineer in charge of a bund, finding the water rising with more rapidity than he was able to meet by the supply of earth, made a wall of the bodies of his laborers, causing them to lie down close to one another on the top of the threatened part of the dam, and thus keeping back the

two inches or three inches of water, which, if unchecked, would soon have wrecked the whole bund, and ruined a wide district, until their places could be supplied by baskets full of earth. It was an original expedient, but it saved the district. What the laborers said about it we have not heard.

The districts of India which are naturally fitted for such works are full of noble tanks, of native construction, some of which are of venerable antiquity. Till within the last thirty years very little was done to keep these important works in repair. In 1827 the Veranum tank was in such utter disrepair that the people were almost in a state of rebellion from want of water. A report that the sum of £3,500 ought to be laid out on it was made in that year; but by 1833 no steps had been taken to carry out the order for the work, and the people were in such a state of discontent that it was feared that it would be necessary to send troops into the district. A large number of tanks have now been put in good order by the Government. In Mysore the condition of these works, under the charge of Commissioners who have a considerable degree of power, is said to be excellent. In Madras there is great room for improvement. In Bombay two new and capacious tanks have been formed by shutting up valleys, one by a masonry bund, the other by an embankment of earth. Each will contain about 140 million cubic yards of water when the waste-weir is closed. But as, during the four months of the monsoon, a tank supplies water to the dependent canals at the same time that it is filling, the water which it preserves from being wasted is more than its actual contents when full. The tanks in question may thus convert to useful purpose as much as 200 million cubic yards of water a piece per annum. The loss by evaporation during the year is estimated at seventy-two inches over the surface of the water area, which will amount, in the cases in question, to about six per cent. of the whole supply afforded by the tanks.

The cost of the tank with the masonry bund, which is near Poona, is not at present accessible. The other, which is near Sholapoor, cost £90,000; of which some £20,000 were spent on the canals for distribution. The capital laid out was thus about £500 per million cubic yards of the contents of the tank, or £370 per million cubic yards of the water actually utilized in a year by its agency.

Near Nagpoor is a site where it would be quite practicable to form a tank that would contain 2,000 millions of cubic yards of water. Such an inland sea would feed the stream of the Godavery for 200 days in the year with an average supply of 400,000 cubic yards of water, which is double the flow to which the river is now reduced in the dry season, thus facilitating the navigation of 500 miles of canal, besides the ultimate application of the water to the irrigation of the crops. The cost of such a work, which Sir A. Cotton estimates at £400,000 would not amount to more than £800 per mile of navigation, or, at seven per cent. to about £70 per mile per annum for supply of water to the canals.

The great special works of the annicuts or dams at the head of river deltas, and of the tanks, or mountain reservoirs, for storing the copious rainfall of the highland districts, are, as we have seen, special features of India. In that portion of the system which lies between the tank and the annicut, we have occasion for works of a kind with which English and Dutch engineers have long been familiar; not that the peculiarities of the Indian climate do not impart a special character to Indian canal work. An Englishman would be apt, on looking at the map of India, to conclude that, in order to conduct an enormous amount of inland navigation, it would only be necessary to put boats on the great rivers. Had this been the case, the natives would not have left it to us to show them the way to do so. In point of fact, while greatly respecting the military power of England, they consider us, as engineers, as little better than savages,—anyway, inferior to some of the native rajahs who constructed the great works of past years. Nor can it be denied that in what, after all, is one of the best tests of the skill of the engineer, namely the production of a given effect with the least expenditure of power, and with the simplest machinery, the Indians have many centuries ago arrived at a *ne plus ultra*. Long before the science of the French engineers had arrived at the fact that the mode in which human labor can be most

efficiently exerted is by man's raising his own weight, the Indians had watered their rice-field on that very principle. We have seen, five and twenty years since, in France, elaborate contrivances for raising earth, at which an English navvy would laugh, but by means of which human labor became cheaper than horse labor. An incline plane was constructed at an angle of between 45° and 60°, and two platforms were connected by wheels, chains, and pulleys, in such a manner that as one ran up the incline the other ran down. On to the platform which happened to be at the bottom the barrow-man wheeled a barrowful of earth, and left it there in the barrow. A couple of laborers quietly made their way up a sort of half-ladder, half-staircase laid up the slope, walked on to the upper platform, which descended by their weight, and thus raised the barrow of earth to the upper level. The daily work of a certain number of workmen thus consisted in walking up the slope and riding down it. It was an easy occupation, but the very ease depended on the fact that the muscular energy necessary to raise so many tons of earth so many feet in height was thus most efficiently exerted. A man can work in this way at the best advantage, just as a horse can do five times the amount of haulage at his natural pace of two miles and a half an hour that he can do at the driven pace of ten miles an hour. In England the work would either have been done by relays of barrowmen, each wheeling the barrow for a run, or by the aid of a horse, pulling the barrow, and in some cases the man who guided it, up a steep incline. The French mode, strange as it looked to a muscular Englishman, was really the cheapest. It involved, of course, some preliminary outlay in machinery. But the Hindoo lays a long plank, notched, to prevent slipping, over the fork of a post which he drives into the ground near a supply of water. That is all his machine, and very often the post takes root, and grows into a tree that shelters the workmen. The water vessel, and the bamboo which attaches it to one end of the plank, the workmen take home at night, to avoid theft. The day's work then consists in something like the English boy's game of see-saw, the man walks along the plank backwards and forwards. As he approaches the tree, the water-vessel dips into the water. As he walks to the other end of the plank, the vessel is raised. The Madras engineers have made careful theories of the statistics of the employment of human power. Sir Arthur Cotton says that the cost of water raised by this contrivance, which is called a picottah, is about the same as that raised by bullocks, being about £1 per 3,000 cubic yards. The great points to admire are the extreme simplicity of the machinery and the exertion of the minimum labor on the part of the workmen.

It is thus tolerably clear that any one who approaches the question of Indian irrrigation and water-carriage, with the lofty idea that we have but to carry the science of our own highly-civilized country to the aid of a barbarous people, and that wealth and ease will follow our footsteps, totally misconceives the nature of the problem to be solved. In very much, of course, the progress of manufacturing industry made by us within the present century, gives us a great advantage over the Oriental who has never seen a steam-engine. But the rapidity with which the Hindoo, still more the Chinese, or the Japanese, will rise, by his great imitative powers, to the level of the European workman, is one of those facts which it would be well for this country if the English workman fully realized. In the Mint works of Madras and Calcutta, Colonel Smith trained native workmen so closely to emulate his English workmen, that he obtained from the former, at the price of an anna, that for which he had to pay the latter a rupee. This is an extreme case, and the craft of the moneyer is one in which the Hindoo might, perhaps, have been expected to excel. But, as a general rule, what India demands at our hands, is rather Governmental facilitation of remunerative works than anything else. Even capital, our great reliance, is not so much the need of India, as confidence. There is abundance of native capital that would be forthcoming for works such as those which India requires, if only the wealthy natives were convinced of the hearty good wishes and sanction of the Government. To those of our readers who have never been out of England, this assertion may seem in-

credible; but those who know the East, or even who know many parts of the South of Europe, are well aware of the slavish terror with which the mass of the people regard even the smallest official. Experience is ample and conclusive to the effect that the natives will hang back from supporting an object which they sincerely desire, if any jealousy or stupidity in the great hierarchy of officials gives them the suspicion that the Government does not really wish that object to be carried out. Convince them of that, and do so by giving that information and that admistrative aid of which the Goverment has the means of disposing, and the degree of local support that will be forthcoming for well-considered schemes, will be quite enough to satisfy the friends of India.

In the case of river navigation, the impulse of the central power is required, from the fact that widely-distant districts of country have a real solidarity of interest which only the central power can comprehend. Thus in the case of the proposed storing of the water of the Godavery this very cause of dispute has arisen. The new tank would be in one district; the main utility of its contents would be in another. But the former district intimates that it would consider the water stored in its valleys as its own, and would consult its own interest in its distribution, heedless of those of the lower river basin. Meantime the Cauvery is comparatively useless as a highway during the very season in which the carrying trade is naturally most active. A wise and comprehensive policy, collecting all the facts of the case, and facilitating administrative action that should most tend to the common good, is thus the prime need of India as regards public works.

The importance of canal development in India is one that cannot be measured in money. It is, indeed, possible to estimate the loss to the State, in mere annual revenue, that is caused by a great famine. But such a calculation, to say nothing of its quiet cynicism, is very far from representing the actual loss incurred by the decimation of a great province. In 1874, in consequence of a famine due to the want of water, about 4,000,000 people were fed by the Government in Bengal for some four months. They must, in that time, have consumed 350,000 tons of grain. This, not at the famine, but at the ordinary price of rice, must have cost £2,100,000. The grain required might have been produced on 700,000 acres of land, by the application of 6,000 cubic yards of water per acre, or 4,200 million cubic yards. The value of this water would thus have been £1 for 650 cubic yards, or more than a hundred-fold the cost of its storing and distribution. In Orissa, in 1866, there was a famine. The idea that it was within the power and the duty of Government to save the lives of the people had not taken root. The official papers state that a million and a half died. The loss of revenue to the Government, at 2½ rupees per head per annum, was £375,000 for the year. At twenty-five years' purchase, this gives a national loss to the revenue of £9,377,000. To save these lives would have required 150,000 tons of grain, costing £900,000, which it would thus have secured a tenfold profit to the Government to provide. But to have raised that quantity of rice would only have required the distribution of 1,800 million cubic yards of water. The value of this water, that is to say, its productive value, would thus have been 260 yards for a pound. Its cost, which by the *picottah* we have seen to be 3,000 cubic yards for the £1, we have found on the great irrigation works to be reduced to 70,000 cubic yards for £1. These are incredible margins between the cost of neglect and the cost of forethought; to say nothing of the vast amount of human misery entailed by what has been shown to be a preventible evil—local famine.

Not only in the production, but in the distribution of food, canals already play no small part in the production of the wealth of India. How very little now needs to be done in order to complete the service of some of the most important districts it is satisfactory to know. At the same time it is all the more urgent that the works in question should be pressed, with the least possible delay. Thus, if the 7,000 miles of canal which have been designed as easily to be constructed in connection with river navigation in India were made (being less than twice the mileage of the canals of the United Kingdom), and if they conveyed

an average traffic of two millions of tons over the entire system (which is the actual traffic of the Aire and Calder), the cost, at one-tenth of a penny per ton mile (which is double that which Sir Arthur Cotton estimates), would be £6,000,000. The same amount of transport by road, at 3*d* per mile, would cost £180,000,000. By railway, at the existing rate of charges, it would be £90,000,000.

It is thus clear that the absence of water communication forms the bar to an immense internal traffic, which would not only augment the wealth of India, but would have a direct effect on the English market. Thus it has been calculated that the wheat which is at this moment selling on the Upper Mahanady at 9*d* a bushel may, on the completion of the designed lines of inland navigation, be landed in England at 2*s* 6*d* per bushel cost price. The effect of this, or of anything approaching to this, immense revolution in the corn trade would be prodigious. From twenty to thirty millions a year would be paid to our own subjects in India, instead of to the United State. A corresponding outlet would be afforded to the goods of Manchester and our great manufacturing centres. Where merchants are now anxious to obtain a reduction of 2*s* or 3*s* per ton in freight by sea to Calcutta, they overlook the fact that is within the power of the engineer to reduce the rate of transport for 1,000 or 1,500 miles in India itself from 1½*d* to one-tenth of a penny for ten miles, or by 150-fold.

The total expenditure upon the irrigation works of the North Western provinces of India, up to the end of 1874–5, has been £4,565,578 sterling (at the valuation of 10 rupees to the pound). Out of this sum £22,197 were laid out on works that have been abandoned, and £675,175 on works under construction, from which no revenue has yet been derived. The balance of £3,836,517, represents works in partial operation, although yet incomplete. These are chiefly from,—viz., the Ganges, Eastern Jumna, and Agra Canals, the Dun, Rohilcund, and Bijnour water-courses, and the Bundelkhund Lakes. Of these the canals alone have cost £3,632,051. In the second series the principal work is the lower Ganges Canal, now in the third year of its progress, on which £622,502 have been laid out. The income assessed for the first year in water rates and miscellaneous income on the partially opened canals was £295,560, to which has to be added a figure of £85,887 credited in the civil accounts as increased land revenue due to the operations of the canals. On the total revenue of £381,447 the working expenses have been £132,493, or 34·6 per cent., a ratio that no doubt will be considerably reduced by the completion of the works. As it is, however, the net revenue is enough to pay a dividend of 6·49 per cent. on the capital expended. These figures include the first year's operation of the Agra Canal, on which the expenditure has exceeded the income. Setting this aside, as a temporary feature, the profit on the works in full operation, has been 7·48 per cent. on the capital expended to the close of the year. On the Eastern Jumna Canal alone, the profit on the outlay has amounted to the high ratio of 29·17 per cent. It will therefore be seen that the latest statistics furnished by the Indian Government, are such as fully to bear out the statements of the advocates of irrigation canals.

It will be a thousand pities if facts like these are shrouded with any discredit by the personal views—not to say whims—of any of those persons to whom we have to look for information as to India. Especially we regret the attacks made on the Indian Government, and on the Indian railways. As to the latter, the wine is drawn, and we have to drink it. More than that, the majority of persons in this country will think that it has been well drawn. To construct 6,000 miles of great strategic lines at one-third the cost per mile of the English railways, and so to work them as to earn a *bona fide* 3½ per cent. on the capital, is not, in our view of the case, bad work. The fact that canals can be constructed at £1,000 or £2000 per mile does not invalidate the position of the railways. But it does give promise of abundant increase of the wealth of India, and that increase will affect the railways advantageously,—whatever be the bulk of goods and number of passengers borne by water. Far more than was the case in England forty years ago has the internal traffic of India to be created. That

it will spring up with immense rapidity we do not doubt. Nor do we hesitate to repeat that the main charm by which the face of India will be furrowed by canals, roads, and irrigation works will be found to be in producing the local conviction that the Imperial Government has that development of the communications and resources of India deeply and truly at heart.

OVERCOMING STEEP GRADIENTS ON RAILWAYS.

By HENRY HANDYSIDE.

Journal of Iron and Steel Institute.

The chief object I had in view, when, in 1871, I first matured the idea of the new system, was to provide a cheap and efficient means whereby the locomotive of ordinary construction might be made available for surmounting steep inclines, and without any alteration or addition to the ordinary permanent way, or alteration in section of rails.

The subject is naturally divided into two parts; the going up, and the coming down, and I propose to describe them in that order.

There is no portion of railway engineering so arbitrary and well defined as the law of inclines.

On all ordinary locomotive lines, the steepest portion becomes "the ruling grade" for the whole line; that is to say, the ruling grade decides the weight of the locomotive, the exact load it can draw on that grade, and the weight of the rails along the whole length of that line, on which that locomotive has to run.

There is no difficulty in apportioning the steam power of any locomotive to the amount of its adhesion, and as this adhesion is solely dependent on the amount of weight which can be put upon the driving wheels of the engine, it follows that the load any engine can take up an incline must be in an exact *ratio* to the weight on the driving wheels, and the angle of the incline.

It has been ascertained by actual experiment, that the limit of adhesion between an iron tyre and iron rail, is on an incline of 1 in 6; or in other words, any locomotive, with sufficient cylinder power, and all wheels motors, will ascend an incline of 1 in 6.

Any very close approach to this limit would be of little commercial value, and the nearest which has been successfully employed, is an incline of 1 in 10, which was worked for three years on the Baltimore and Ohio Railway, the engine taking up a load as heavy as itself—this fact is recorded in Mr. Isaac's interesting paper, read before the Institute of Civil Engineers, on November 23rd, 1858.

Thus it appears evident that it is not the steam power of a locomotive that is wanting, but the adhesion between its wheels and the surface of the rails.

To supply this great want has been the object of locomotive engineers from the earliest days of the steam engine, and very numerous and varied have been the mechanical contrivances brought forward, many of them performing all requirements, but laboring under the disadvantage of additional cost to permanent way, greater weight and complication in the engine itself, and all being obliged to devote their steam power to ascending the incline at the same time with the load.

It is on this point that my system differs from all others ever used. I use any ordinary locomotive, applying thereto a winding engine and steel wire rope, or chain, and peculiarly constructed gripping struts, which also perform the duty of a most powerful brake when descending.

The engine having hauled its train to the foot of an incline, of say one in twelve, disconnects itself, but leaving the end of the wire rope fast to the train, it proceeds up the incline for any desired distance, but within the limits of the length of the rope.

The struts, having been released by the engine driver, immediately come into play, firmly grasping the heads of the rails, and thus the engine becomes at

once a stationary winding-engine. By the application of steam to the winding cylinders the train is drawn up close to the engine.

If the incline is of too great a length to be surmounted in one lift, a similar pair of gripping struts are fitted to the last wagon or guard's van of the train, and as they act quite automatically, the train is firmly held in its place whenever the winding ceases.

This automatic action of the struts, when fully understood, will recommend itself for adoption in all cases where retrograde motion is to be feared on steep inclines; and even on those in this country on some of the main lines ranging from one in forty to one in sixty, and on which such disastrous results have followed from the breaking of couplings or draw bars.

In laying out a new line for my system, I prefer to keep the steep inclines straight, and with the limit of wire-rope the engine can carry. I prefer not to exceed 300 yards, each incline to be followed by a piece of level, which may be taken advantage of for curves. Thus, the ascent of the line is made by a succession of steps, and resembling in its action the working of a canal with locks.

My chief reason for keeping the inclines straight, is to dispense with cast iron guide pulleys, which are objectionable, entailing great friction and wear and tear to the rope; if, however, the nature of the ground is such that the incline and curve must be combined, then the ordinary guide-pulley may be resorted to.

When the inclines are kept straight but very few wooden rollers are sufficient, the rope bearing very lightly and only for a portion of the lift; this is due to the rope being coupled to the drawbar of the wagon and the top of the winding drum, at least three feet six inches from the level of the ground.

It is evident that by this transformation of an ordinary locomotive into a stationary winding engine, it combines and uses all the advantages to be derived from either or both.

Long experience, apart from the theory of the question, has determined the economy of the rope system, and the nearer the vertical lift is approached, the greater the economy of working—but the risk increases in equal proportion.

It is an easy matter to provide against an accident when going up, either an incline or vertical lift, but the descent has to contend with the formidable powers of gravitation and accelerated momentum.

This brings me to the second part of my subject, "the coming down."

As I have mentioned, I prefer to cut up my line into steps—keeping each steep incline of a comparatively short length. By this means I can reduce the danger to be anticipated from accelerated momentum; for, supposing the brakes to be overcome, which would never be the case until probably one-third, or one-half of a short incline had been descended, then all the speed any train could acquire sliding to the foot of the incline would soon be overcome when the train came on to the level.

We know by practice that all railway stock has an adhesion to the rails equal to one-fourth of its weight, although many engineers in this country do not think more than one-sixth ought to be relied on.

Taking even the latter as a datum for braking purposes, it is clear that any railway wagon or carriage, with proper brakes on all the wheels, could descend an incline of 1 in 12 with perfect safety, so long as a certain speed was not exceeded, but the great danger is that this speed might be exceeded, even under the charge of the most experienced brakesman, who would have no greater retarding power to apply to, and that train would "run wild."

Foreseeing that this evil must be provided for, I have so constructed my gripping strut that it acts as a brake of the most powerful nature when coming down hill.

The construction of this brake causes it to press, not only on the top of the rails, but also in as great a degree on the sides of the heads of the rails. To provide against wear, the three bearing surfaces of each shoe are made as renewable pieces of iron or brake metal, which can be removed and replaced in less than 20 minutes.

This brake will work on any section of rail, but it must be apparent that the

deeper and flatter the sides of the tops of the rails are the greater will be the effect produced with the least amount of wear on the renewable faces of the brake. Some who have seen the action of this brake, having at once admitted its great retarding power, have qualified the praise by saying it could not be made generally available on our lines on account of "points and crossings."

This, at first sight, appears a most formidable objection, but, like every mechanical difficulty, it ought to be, and has been surmounted.

In the case of the application of my brake to a locomotive, Mr. Walker (of the firm of Fox, Walker, and Co., Bristol) has made a very ingenious adaptation of steam power, by which the brake is instantaneously and automatically lifted off the rail when coming close to a point or crossing.

A similar arrangement, in the case of a guard's van, can be secured by the use of compressed air, or even by ordinary mechanical appliances.

Although I can fully agree with the general opinion that, "it is desirable that brakes should work equally well over points and crossings," I still think it will be admitted that, although danger is generally to be anticipated in the immediate vicinity of points and crossings—that in nine cases out of ten, when brake power has been insufficient, the engines and trains were running on clear rails, and might have been brought to a stand before the points and crossings were reached, if the driver and guard had been in possession of some greater and reliable retarding power.

By the application of this brake to a locomotive, its retarding power is nearly trebled, an advantage of no small importance, especially when under the control of the driver, who is the sole and proper person to have full control over his engine and train.

All the retarding force which can be derived from the top surface of the rails has long been known and utilized to the utmost, as it has often been found insufficient on our ordinary lines, and as it would certainly be quite insufficient on steep inclines, I have ventured to utilize a portion of the ordinary rail which can well afford to take its share of work when required.

My great object in bringing the subject of overcoming steep gradients before your notice, is to prove that by this simple adaptation of certain well-known machines, in combination with various novel appliances, a railway system is produced which will enable the engineer to undertake the construction of mineral lines at a much lower rate than heretofore.

I do not say that the cost, mile for mile, will be less in all cases, as compared with a line laid out with ordinary grades; but it will enable the engineer to take a more direct route, and effect a large saving in actual distance or length of permanent way—generally as much as sixty per cent., and after giving him the power of taking his line in certain directions to suit the wishes of land-holders, in some cases, thus removing the chances of a strong opposition, which, in several instances, has prevented an easy access to districts, known to be rich in mineral wealth.

REPORTS OF ENGINEERING SOCIETIES.

American Society of Civil Engineers.—The last number of the Journal of this society is of double size and of proportionate value. In addition to the reports of committees and officers, it contains such summaries as are incident to the close of the fiscal year: The present number includes a full report of the addresses and subsequent discussions on the subject of technical education at the joint meeting of the Civil Engineers with the American Institute of Mining Engineers at Philadelphia, in June, last.

To American students this report, embodying the views of eminent American Engineers on the subject of education, is the most valuable treatise yet published. We hope to see it published in such form as shall place it within easy reach of all.

The annual reports all indicate a peculiarly vigorous condition of the Society.

The annual convention is to be held in New Orleans in April.

IRON AND STEEL NOTES.

Compressed Steel.—Speaking at the Iron and Steel Institute on the application of hydraulic power in forging, Sir Joseph Whitworth stated that his firm had recently completed two twin screw shafts for the *Inflexible*, 283 feet in length, seventeen inches in diameter, and cast with a nine inch hole through them. These shafts were made of compressed steel, and weighed sixty-three tons, instead of ninety-seven tons if made of iron,—a reduction permitted by the great strength of the compressed steel. He further stated that on applying the

hydraulic pressure, a column of metal is reduced 1 8th in less than five minutes,—a remarkable indication of the effect of pressure in expelling air-cells. The strength of the shaft was forty tons to the square inch, and its ductility or power of extension was thirty per cent. of its length. By using compressed steel, the driving round of thirty-four tons was saved during the whole life of the engines.

Steel Rails in Germany.—Herr Funke, of Cologne, has contributed to the journal of the German Railway Union some valuable information upon the relative value of steel and other rails. Experiments, commenced in 1864, have been made with rails of different materials, but laid under similar conditions upon the Cologne and Minden line where the traffic is heavy. The rails tried were 150 fine-grained rails, 150 cemented rails, twelve of Funke and Elber's puddled steel rails, twelve of Hoesch and Sons' puddled steel rails, 149 of Hoesch and Sons' Bessemer rails, 147 of Krupp's Bessemer rails, and 150 Bessemer rails from the Hoerde Works. On the 1st of October, 1875, after eleven years' service, 115, or 76.7 per cent., of the fine-grained rails have been renewed; ninety-five, or 63.3 per cent., of the cemented iron rails; four, or one-third, both of the Funke and Elber's and the Hoesch and Sons' puddled steel rails, and of the Bessemer rails; seven, or 4.7 per cent., of the Hoesch and Sons; six, or 4.1, of the Krupp; and two, or 1.3 of the Hoerde rails; of the Bessemer rails one broke through the bolt holes, one scaled off on the head, and the other three were beaten down and flattened out at the joints, without being entirely spoiled. Pieces were cut from the ends, and then they were used again in sidings. The flattening at the joints is charged to the form of the rails, which have a pear shaped section, and could not be fastened firmly at the joints. Taking the mean of the Bessemer rails, the necessary renewals after ten years service was 3.4 per cent., against 33.3 per cent. of the puddled steel, 63.3 of the cemented, and 76.7 per cent. of the fine-grained rails. The average tonnage, excluding engines, over these rails was about 18,000 tons per day. The result of this trial was the adoption of Bessemer steel. Altogether the company has had, in the eight years from 1868, to 1875, 504,634 different Bessemer rails, which at the close of this period had been in use on an average two and a half years. In that time 1625 had been replaced, or 0.322 per cent. of the whole number. At the end of 1875 the iron rails had been in service on an average 6.98 years, and within that year 6¾ per cent. of them had been replaced, while in the same year only 0.2 per cent. of the Bessemer rails—in use an average of 3.8 years—had been renewed. Experience has not shown that steel rails break easier than iron ones; 0.238 per cent. of the whole number had broken down to the end of 1875. More of steel than of iron break very soon after they are laid, often under the first train that runs over them. Since 1867 the company have bought 17,600 tons of iron rails and 153,000 of Bessemer rails; but since 1872 it has bought nothing but Bessemer rails.

Hot Short Steel.—A Mr. F. Valton has been for some years manager of certain ironworks in Siberia which are the property of Prince Demidoff. Bessemer plant has been recently erected at these works, and in order to test the quality of the metal made, the ordinary continental practice was pursued. A small ladleful of metal was taken from each "blow," and forged at once into a little bar, after which it was re-heated very hot, and bent over and hammered down on itself. The bar cooling down all the while, each doubling was done at a different temperature. Working in this way, Mr. Valton found that a bar which bent quite well at any temperature from a red down to a blue heat, invariably broke at the latter temperature. If the bar were cooled down still further, no fracture took place. In other words, this steel was perfectly tough, sound, and good at any temperature above or below from 360 to 400 deg. Cent.—that is to say, the temperature at which a piece of wood brought in contact with the hot metal just begins to carbonize. At first Mr. Valton and his assistants believed that they must be deceived; but the most careful research proved that there was no deception about the matter, and that the steel they made was really extremely brittle at and about a good blue heat. The natural conclusion was that this phenomenon was limited in manifestation to Prince Demidoff's Siberian steel, and that the defect was probably due to the presence of minute quantities of copper in the pig. But to settle the question Mr. Valton procured specimens which it was certain must be unlike the defective metal. These specimens consisted of Tagilsk charcoal irons, made as far back as 1770, and kept in a museum; Oural irons, both bar and sheet; mild Bessemer and Martin steels from the Terrenoire Works; Mild English steels; and, finally, English rails of good quality. All these specimens, hammered, rolled lengthwise and then across, gave precisely the same results. They were all brittle at 360 to 400 deg. Cent. Mr. Valton naturally concluded that he had made a somewhat curious discovery; when some of the men, finding out what he was about, told him that there was nothing novel in the matter, as they had been familiar for years with the facts, and that, in working fine Russian iron under the hammer, it was necessary to stop hammering when the plate had fallen to a given temperature, guessed by the workmen by the eye. The hammering could not be renewed with safety until the metal had fallen still further in temperature. Further researches tend to show that the phenomena are only manifested by good metal, or perhaps it would be more correct to say, that they are not displayed by bad irons or steels. Mr. Valton has read a paper on the subject before a Russian learned society, in the course of which he said, "Iron and steel may, in a large number of cases, have to endure strain at a temperature analogous to that I have spoken of above. Boiler sheet, fire-arms, or badly oiled axles, may, any of them, rise to a heat over 300 deg. Cent., and the metal may then, in the most unforeseen manner, suddenly lose more or less of its power to resist strain,

i. e., its strength. I think there is fair ground for making a series of methodical experiments on the loss of strength on the part of iron and steel under the conditions I have pointed out. If the property noticed is a real and generally recurring one, it should be known as generally, so that all interested should be put on their guard against the possibilities of accident which may occur therefrom." It will be seen that in this case Mr. Valton's men had known for some time what he was at considerable trouble to find out.—*Engineer.*

RAILWAY NOTES.

THE BEIRA RAILWAY.—The Portuguese Government have sanctioned the project for the upper Beira Railway, which is to unite the existing line between Lisbon and Oporto, and thus shorten the journey from Paris to Lisbon *via* Madrid by a whole day. It will leave the Portuguese line near the Coimbra station, traverse the whole of the Mondego Valley, and terminate at the Spanish frontier, where it will join the Salamanca Railway. The construction and working of the line have already been advertised for tender, and the competition will be open for sixty days from the 22d June. The conditions, according to the *Diario do Governo*, are rather remarkable. The first step for the competitor is to deposit at the Bank of Portugal the sum of 750,000f,—£30,000—the base of the tender being the amount of the subvention per kilometer. The successful competitor will have to increase his deposit at the bank to 1,500,000fr.—£60,000—while the remaining deposits may be withdrawn. The concessionaire, whether an individual or a company, will undertake, at his own risk, the construction of the line with the expropriations, earthwork, bridges, laying the rails, stations, repair shops, &c.; he will supply, maintain and renew the locomotives, goods wagons, passenger carriages, &c.; he will, in fact, provide all the permanent way and rolling stock, as well as telegraph the whole length of the line. The railway is to be in accordance with the plans and sections approved by the Government, and is only to be a single line at present; thus the tunnels are to be constructed for a double line. The railway and everything connected with it is to be the property of the Government, but the rolling stock and the stores will belong to the concessionnaire, with the understanding that they are not to be removed except to be replaced for the advantage of the public service. In return for the obligations which the concessionaire takes upon himself by this contract, the Government concedes for ninety-nine years the working of the rai way, as well as any branches which may bring traffic, the concessionaire undertaking at the end of the time to give up the railway in good working condition, the rolling stock and the stores to be taken at a valuation. At any period after the first five years, the Government may purchase the whole concession on certain conditi ns provided for. The subsidy, which forms the basis of the competition, will be paid at the opening of the line; but this does not apply to branches, for which the Government will neither grant a subvention nor guarantee the profits. If the concessionaire should not construct branches, the Government reserves the right to make them or to concede them to other companies. The Government undertakes not to grant a concession, during the ninety-nine years, of any parallel line at less distance than forty kilometers (twenty-five miles), without the ascent of the original concessionaire who will besides enjoy the following advantages:—He will be exempt from all tax for the first twenty years, and the Government undertakes not to impose any special contribution during the whole of the ninety-nine years; he will have the entry free of taxes of all articles necessary to the construction or working of the line until its completion; and this exemption will be continued during the first two years of working as far as engines and fuel are concerned; lastly, the Government grants all the land belonging to the State which may be required for the line, as well as all buildings and woods that may exist upon such land, but expropriations must be settled privately or by law. The passengers, goods, and cattle rates, will be established on the base of those now in force on the Northern and Eastern of Portugal lines, which belong to a French Company.

WORKING STEEP GRADES.—A novel system of working trains on steep railway gradients by locomotive engines has been patented by Mr. Graham Stevenson, of the firm of Dick and Stevenson, Airdrie, and Mr. John Reid, manager of the Provanhall collieries, near Glasgow. The apparatus has just been erected at the collieries named, and put into operation during the past week.

The incline selected for the first application of this system leads downwards from the main rails of the Baillieston branch of the Caledonian Railway to two pits belonging to these collieries, about three quarters of a mile distant, with an average gradient of about 1 in 13, and ranging between 1 in 11 and 1 in 15. About six years ago Mr. Stevenson's firm constructed two powerful tank locomotive engines to work this incline and marshal the trucks of coal before entering the main line; and during that time the engines have performed the work with remarkable success, considering the extraordinary gradients over which they had to travel —the steepest, perhaps, with one exception, worked by locomotive power in the kingdom.

The traffic from the pits has so increased of late as to make it impossible for the engines to overtake it, and the construction of a third engine, or some other means of assisting the two, came to be a matter for consideration. With the latter view it was proposed to erect a small stationary engine, working a wire rope, to contribute to the power of the locomotives, or occasionally to draw a few trucks independently of them; but in place of a stationary engine, the idea of stationary gearing which might be acted on by one of the locomotive engines, occurred to the patentees, and this idea was realized, as we have stated, and has been put into practical operation recently. Since that time the machinery has been inspected at work by a large number of engineers

and colliery proprietors, many of whom have expressed decidedly favorable opinions regarding it. The efficiency of the system, together with the simplicity of the arrangement, will probably insure for the system a large adoption where the nature of the ground involves inclines of exceptional steepness, and at other parts admits of the use of locomotives. In such instances stationary engines will be entirely avoided, and no additional working expenses incurred more than if the whole line were worked straight through by locomotives.

The winding drum and its gearing are mounted in suitable bearings on framing fixed in a stone-cased excavation below the line of rails on which the locomotive is brought to the spot. The shaft of the winding drum has fast on it a spur wheel in gear with a pinion on an intermediate shaft, which has also fast on it a pinion in gear with a pinion on one of a pair of shafts. These shafts have wheels fixed on them, with their uppermost parts at the level of the rails, and with cranks on them connected by rods. The rails are cut away at the parts where the tops of the wheels are, and when the locomotive, having two pairs of coupled wheels, is run into position up against a buffer bar, and secured there by a screw, its four wheels rest on the four wheels below, the entire weight of the locomotive serving to impart driving power by adhesion. Then, on the locomotive being made to drive its own wheels, these, acting frictionally on the wheels below, drive the winding gearing. The rails form part of a siding, whilst the winding drum is on the line of the incline. When the train is brought to the top, the locomotive is freed from its anchorage, runs out, and engages the train on the level, disposing of it as desired. In lowering the empty trucks down the incline, the pinion is disengaged, and the drum controlled by the friction strap and lever. The amount of work capable of being performed with the new arrangement is four times greater than before, when the delays consequent on running the locomotives up and down the incline, shunting, coupling, standing, &c., are taken into account, the cost of labor remaining the same, whilst the wear and tear of the rails and engines is very greatly diminished.

ENGINEERING STRUCTURES.

THE TAY BRIDGE.—At the last meeting of the Edinburgh and Leith Engineers' Society, a Paper was read by Mr. A. Grothe, C.E., on the appliances used at the Tay Bridge. He described the piers, which are founded upon rock, and which consist of two cylinders (each nine feet in diameter), and the method of building, floating out, and lowering them into the place which they have permanently to occupy. Afterwards Mr. Grothe noticed the construction of the piers for the 245 feet spans, which are founded upon a layer of gravel sixty-three feet under the river bed. These cylinders are thirty-one feet in diameter, and, when floated, were hanging between two barges forty feet high, and having a weight of nearly 200 tons. The lower twenty feet of them have a lining of brickwork to give that part of the pier stiffness and weight. The top part consists of iron, and is only temporary. These are lowered to the river bed, and then further sunk by pumping the sand out from the inside by an apparatus invented by Mr. Reeves one of the assistant engineers at the bridge, which exceeds all other means, previously used, in cheapness and efficiency, and will, it is thought, as it becomes known, supersede in many cases other modes of dredging. Lastly was described the construction and floating out of a heavy block of brickwork on to the top of the filled up cylinder. In answer to a question, Mr. Grothe stated that, in his opinion, it would not have been judicious to build the bridge for a double line all at once, inasmuch as it would have added seventy-five per cent. to the cost, and at least two years to the time of constructing. As it is, a second bridge can always be built by the side of the first, and at a cost not exceeding the seventy-five per cent., the experience gained in building the first representing a saving of twenty-five per cent. for the second. In the meantime the company have the use of the present bridge, and save a large sum as interest on capital while building.—*Architect.*

RAILWAY STATION ROOFS.—Messrs. Andrew Handyside & Co., of Derby and London, are at present engaged in making the iron roofs of four railway stations all of some importance and interest. At Glasgow, for the Union Railway at the new St. Enoch's Square Station, the roof is a large single span of 198 feet and 518 feet long, of somewhat similar construction to that of St. Pancras, London, which is 240 feet span and 689 feet long. The main ribs in the Glasgow roof weigh thirty-seven tons each, and the total weight of ironwork is 1,460 tons. Mr. Blair (since deceased) was the engineer under whom the construction of this station was commenced. Messrs. Handyside & Co. expect to finish the ironwork soon after Christmas, and the station will be completed during the summer. At Manchester the three railway companies, the Midland, the Great Northern, and the Manchester, Sheffield, and Lincolnshire, are about to build a large joint station under the superintendence of Mr. Charles Sacre, the engineer of the last-named company, and have ordered from Messrs. Handyside & Co. the iron roof. This roof again is of the same kind as at St. Pancras, but larger than at Glasgow, having a span of 210 feet and a length of 550 feet, the weight of ironwork being no less than 2,400 tons. This station is to be completed in 1878. At Middlesbrough a new station is being constructed for the North-Eastern Railway Company from the designs of Mr. W. Peachey, architect to the company, and the roof, which Messrs. Handyside & Co. have been making at Derby, is now nearly all erected by them at the site.

From advance proofs of the new edition of Mr. Ewing Matheson's "Works in Iron" which is to appear at Christmas, we have the following particulars of this roof:

"The station is 309 feet long, covered for 180 feet of that length by two spans, one of seventy-four feet (in the clear), and one of

forty-three feet two inches, and for the remainder by the larger span only. The arches are pointed in a somewhat Gothic style, and are not tied or trussed, the thrust outwards being taken by the walls, which are sufficiently but tressed by outer buildings. The main ribs are placed twenty feet two inches apart, and spring from stone columns or pilasters attached to the walls, and from pairs of iron columns where the two spans meet. The pairs of iron columns are connected longitudinally by wrought-iron box girders pierced and ornamented with pateræ, and with ornamental cast-iron spandrils. The ribs for the seventy-six feet span are formed as triangulated ribs two feet deep, with flanges twelve inches wide, the upper flange being composed of two plates $\frac{3}{8}$ inch thick, rivetted to a T iron 5 inches × 4 inches × $\frac{1}{2}$ inch, and the lower flange of one plate $\frac{5}{8}$ inch thick attached to a similar T iron. The diagonals are channel bars $2\frac{1}{2}$ inches × $1\frac{1}{2}$ inch × $\frac{1}{2}$ inch. There are eight lines of purlins in the large span, each made as a lattice girder 1 foot 6 inches deep, widened out at the ends to the width of the arched ribs which it intersects. Upon the purlins are placed intermediate rafters, which are single T bars 4 inches × 4 inches × $\frac{1}{2}$ inch, the feet of these rafters resting at one side on the wall, and on the other upon the girders between columns. At the crown of the arch is a raised ventilating roof formed of cast iron spandrils placed on the main ribs, having wood louvres at the sides, and covered by slate on timber rafters. From the springing to the second line of purlins the roof is covered with slates or boarding, and from these upwards to the sides of the ventilating roof by glass in iron sashbars. The glass covering terminates at the distance of one bay from each end, the portions thus left being covered with zinc upon boarding. The main ribs for the forty-three feet span are similar to the large ribs but smaller, the rib being eighteen inches deep, and the flange plates nine inches wide. There are six lines of purlins, but these are only one foot two inches deep, the intermediate rafters being similar to those in the larger span. At each end of the station two main ribs are placed close together to carry the screen. These screens are formed of wrought-iron framing glazed wooden sashes, and reach to within fifteen feet three inches of the rail level. There are some small side roofs, and other minor structures, but exclusive of these, the weight of the ironwork described above is as follows:

	tons.
In main ribs for large span.....	155
In purlins " "	55
In intermediate rafters for large span.	20
In ventilator and other ironwork.....	26
In main ribs for small span.....	30
In purlins " "	20
In intermediate rafters for small span.	9
In box girders between columns.....	10
In other ironwork.....	5
Eight pairs of cast-iron columns.....	20
Cast-iron spandrils between columns and longitudinal stays between principals.....	52

The gutters are of lead,

A new terminal station is being constructed at Cape Town, South Africa, under the superintendence of Mr. R. E. Brounger, engineer to the railway company there. The same type of arched roof as at St. Pancras has been adopted but on a small scale, as the span is but seventy-seven feet and the length 256 feet nine inches, divided into thirteen bays of nineteen feet nine inches. In this case a few manufacturers were asked to submit designs to Mr. C. H. Gregory, who acts for the railway company in England. The design of Messrs. Handyside & Co. was accepted, they having reproduced, with certain modifications, the roof over the Drill Hall at Derby which they erected in 1870. The Cape Town roof will be covered by zinc on boarding, except at a raised ventilating roof in center, which will be covered with glass. The ironwork will weigh nearly 200 tons.

THE MARGUERITE BRIDGE AT BUDAPEST.—The preparation of plans for this great work was undertaken in 1871. The choice of system adopted was left to the concurrent opinion of the engineers; but the Government imposed the condition that the openings should be sixty-seven meters wide, and fourteen meters high above the "zero" of the scale, so as not to hinder navigation. More than thirty-five plans were sent for competition; those of Ernest Gouin & Co., of Paris, were adjudged the best, and they were awarded a prize of 10,000 francs.

The contract for the construction was signed in the spring of 1872, and the work itself commenced in 1873; the formal inauguration of the bridge took place on the 30th of April last.

The total length of the bridge is 570 meters, and its width 17 meters; this bridge is formed of six arches, three at each side of the river, of which the openings are respectively 74.83 meters and 88 meters.

The centers have a radius of 135 meters; they are of wrought iron, and bear plates on which rest the Macadam and the wooden pavements.

The construction consumed 7,000,000 kilog. (15,400,000 lbs.) of wrought and cast iron, 40,000 cubic meters of masonry, among which were 4,500 cubic meters of granite, and 5,000 of other kinds of cut stone.

The iron-work for the centers was made in the shops of the Batignolles Construction Society, under the direction of Mr. Gouin; they were carried to Budapest directly by railroad, without transhipment. The granite came from the Bavarian frontier. In order to give the bridge a monumental character, the piers were ornamented with allegorical figures, three times the size of life; and with high candelabra of cast metal, bronzed.

The architect of the royal palace, Mr. Chabal Wilbrod, was charged with the architectural work of the bridge; the sculpture is by Thabard, and the cast ornaments by Durenne. The designs and calculations were made by Mr. Godfernaux; finally, the entire surveillance of the works at Pesth were confided to Mr. Fouquets, chief engineer of the house of Gouin & Co.—*Polytechnic Review.*

ORDNANCE AND NAVAL.

JAPANESE WAR SHIPS.—The Imperial Japanese Government is having an ironclad corvette built in this country. She is of 3,700 tons displacement, 220 feet length between perpendiculars, 48 feet breadth, extreme, and 28 feet 8 inches depth in hold. Her engines are to be on the compound principle, twin screws, with horizontal cylinder and surface condensers. They are to develop 3,500 indicated horse-power, and are estimated to drive the ship at 13 knots. The armament is to be supplied by Krupp, and will comprise four 24 cm. (9½ inch) 15-ton guns, to be carried in a midship battery on the main deck, and two 17 cm, (6⅔ inches) 5½-ton guns on the upper deck. The upper deck guns are carried amidships and are arranged to fire right ahead, on the broadside, and right astern. They are unprotected. The battery guns are placed at the four corners of the battery, and have very considerable fore and aft training in addition to the broadside fire. The armor on sides is 9 inches at the water-line and 7 inches elsewhere amidships; on the battery 8 inches at the Port sills and 7 inches elsewhere. The vessel is to be barque-rigged, with about 12,000 square feet of plain sail. The same Government is also having built here two composite corvettes, which are to have a thin strake of armor (4½ inches) at the water-line in wake of engines.

THE CHILIAN IRONCLADS ALMIRANTE COCHRANE AND VALPARAISO.—The Chilian ironclads, Almirante Cochrane and Valparaiso, are sister ships, built from Mr. Reed's designs by Earle's Shipbuilding and Engineering Company, Hull. They were completed last year. The principal dimensions are—length between perpendiculars, 210 feet; breadth, extreme, 45 feet 9 inches; depth in hold, 28 feet 10 inches; displacement, 3,400 tons. The engines are by Messrs. John Penn and Sons, of Greenwich, and are twin screw on the compound principle, with horizontal cylinders and surface condensers. They develop collectively 3,000 indicated horse-power, giving a mean speed of 13 knots. The armament consists of six 12½-ton guns by Sir W. Armstrong & Co., in a midship battery. The battery is arranged with embrasures, so that the foremost gun on either side can fire right ahead, and the aftermost gun on either side right astern, with sufficient training to enable them to fire slightly abaft and before the beam respectively. The midship gun on either side also fires from an embrasure port which gives it a training of from 20° abaft the beam to 70° before it. The armor on sides is 9 inches at the water-line and 6 inches elsewhere amidships, tapering forward and aft. On the battery the armor is 8 inches at the port-sills and 6 inches elsewhere. Protective deck plating ¾ inch thick is fitted before and abaft the battery on the main deck. These ships are barque rigged, and carry 12,000 square feet of plain sail.

DOING IT QUICKLY.—Some extraordinarily rapid passages across the Atlantic have been recently made by the steamships of "The White Star" line. The Britannic is really at this moment the fastest ocean steamer afloat, as will be seen from the following record of her recent voyages. Under the command of Captain Thompson, she has for four voyages in succession, steamed from Queenstown to New York, and *vice versa*, under eight days, maintaining a remarkable uniformity of speed. The following is the abstract in question:—

OUTWARDS.

Voyage 1876.	d.	h.	m.
10—June	7	16	36
11—July	7	19	57
12—Aug.	7	20	46
13—Sept.	7	17	37
Average	7	18	44

HOMEWARDS.

Voyage 1876.	d.	h.	m.
10—June	7	19	48
11—July	7	22	31
12—Sept.	7	22	55
13—Oct.	7	16	23
Average	7	20	25

On the four outward trips the Britannic ran a distance of 11,216 nautical miles, being an average of 2,804 per trip, which gives a speed of little over fifteen knots per hour, or 360 knots per diem. Homewards she steamed 11,549 nautical miles, or 2,887 per trip, equal to 15.32 knots per hour, or 367.68 per diem. We believe there is nothing on record to parallel this performance. It is fair to add that the success of the ship is in great part due to the efficiency of the four cylinder compound engines, fitted by Messrs. Maudslay & Field to the Britannic. These engines are of the overhead type, the high-pressure cylinder being above the low-pressure cylinder.

THE 80-TON GUN.—The Committees on Heavy Guns and Explosives entered in December on a series of experiments with the 80-ton gun at Shoeburyness with a view, however, of testing not so much the gun itself as the service projectiles. The programme consisted of five rounds of common shell, fired over water to try the strength of the shell; five rounds of Palliser projectiles, fired over the sands for range and accuracy; and two rounds of common shell, fused and filled with powder, fired against a wooden target to test the efficacy of the fuses. The principle on which these fuses are constructed is that of a loose detonating ball in a small chamber. When the shell is suddenly checked in its flight by contact with any object, the ball is thrown forward against the front of the chamber and exploded, igniting the powder-charge and bursting the shell. To this end, however, it is necessary that the projectile shall receive a check; and as it is doubtful whether the unarmored sides of wooden ships would interpose any appreciable obstacle to the passage of a 1,200 lbs. shot impelled by the heavy charge of the 80-ton gun, it is necessary to make investigations, and if the fuses fail to act under circumstances which are liable to occur in action, they will have to be made more sensitive. The firing on Wednesday was intended to test the gun for

range and accuracy, especially when the projectiles were fitted with Lieutenant Gould-Adams's automatic gas-checks. It was necessary that the tide should be well off the sands and the distant range clear before practice could begin. There was considerable delay before the inevitable coasters could be got well away from the probable path of the projectiles, but when everything was finally ready the gun was laid at an elevation of four degrees. Judging from the time of flight, which was carefully taken by Captain O'Callaghan as 6.9 seconds, the shot must have travelled about 3,900 yards before striking the sand. As this is some 200 yards in excess of the distance reached with the same elevation when the gun was last tried, it may fairly be assumed that the new gas-check had something to do with the result, especially as each of the succeeding rounds occupied within a fraction the same time in its flight. With the second round there was considerable delay, caused by a slight defect in the loading-gear and the failure in two or three of the exploding tubes. When the second and third shots had been fired, however, the wonderful accuracy of the huge gun was clearly demonstrated, as examination showed that these two shells had fallen on the lip of the crater ploughed in the sand by the first projectile. With the fourth and fifth rounds, however, even better results were obtained, the shells falling absolutely in the original crater. The gas-checks answered perfectly, with the exception of one round, when the flanges failed to clip and the metal ring became detached from the shell.

BOOK NOTICES.

ANALYSE INFINITESMIALE. DES COURSES DANS L'ESPACE. Par M. L'Abbe Aoust Paris: For sale by D. Van Nostrand. Price $4.40.

This is designed to satisfy the rapidly increasing taste for works in the highest analysis.

The work is divided into two books each of which is subdivided into sections and chapters. A knowledge of the most advanced Analytical Geometry of our colleges is necessary to read with satisfaction the present work.

YACHT DESIGNING: A Treatise on the Practical Application of the Scientific Principles upon which is based the Art of Designing Yachts. By Dixon Kemp. London: The Field Office. For sale by D. Van Nostrand. Price $31.50.

To judge by the dimensions of this volume we should conclude that Yachts were to be classed among the highly important, if not absolutely necessary, adjuncts of civilized life.

The work is a large quarto and unexceptionable in its mechanical execution. The illustrations are plain, but apparently carefully exact and made with reference to aiding in practical designing and building.

There are many applications of the rules fully worked out, and embodying as these rules do the elementary principles of wave lines and resistances to bodies moving through water, have a wider application than that of the Author's subject.

Many details of celebrated Yachts are given both by text and plates.

NOTES ON LIFE INSURANCE. By GUSTAVUS W. SMITH. Third Edition: Revised, Enlarged and Re-arranged. New York: D. Van Nostrand. Price $2.00.

No work on this subject has earned such trustworthy encomiums as the earlier editions of this book.

The subjects in their order are presented in the following table:

Part I Theory—Net Premiums; Trust Fund Deposit or "Reserve"; Amount at Risk, Valuation of Policies; Annuities; Construction of Commutation Columns; Joint Lives.

Part II. Practical Life Insurance—General Management; Variety in Plans of Insurance; Gross Valuation; Net Valuation; Disposition of Deposit, when Renewal Premium is not paid; Annual Statements.

Appendix—Net Premuims; Deposit; Amount at Risk; Annuities paid oftener than once a year; Summary; Formulas and Tables. The Appendix is a mathematical discussion of the above topics.

POCKET BOOK ON COMPOUND ENGINES. By N. P. BURGH. London: N. P. Burgh. For sale by D. Van Nostrand. Price $3.75.

To feel any confidence in Mr. Burgh's formulas or tabulated results, the reader should carefully omit to read the Author's First Chapter. A sample or two will sufficiently explain the reason of this recommendation:

"Steam is an elastic gas of more or less density, according to the proportions of its constituents—as, for example, should the heat be reduced by cooling, the same quantity of water is increased *in its effect*, and thus elasticity is reduced, the pressure of water in steam being in all cases a known constant, while the pressure of heat is more or less increased or reduced by circumstances."

Again: "Let us think, now, what keeps this globe of ours in motion? Why light! as, for example, see Crooke's Radiometer." Then comes the question, Where does light come from? "Why from Electricity, which is the gift of the Great Creator."

The practical science of Mr. Burgh is, however, much better than his theory. There is no doubt but he enjoys lucid intervals when he gets squarely down to his figures, and his book contains much that is very valuable.

WEATHER CHARTS AND STORM WARNINGS.—By ROBERT H. SCOTT., M. A., F. R. S. London: For sale by D. Van Nostrand. Price $1.75.

A small treatise on an extensive subject. It contains a brief discussion of the theory of Cyclones; too brief to be at all satisfactory to an American reader, who is familiar with the fact of the detection of the first development of a storm and the record of its progress for many hundred miles.

The instruments employed in observation are briefly described and some minature weather maps of Great Britain are given. Were it not for these maps which exhibit some roughly drawn isobaric lines, it might justly be inferred that the science of meteorology in England had

advanced just to that point at which the theory that the weather changed at the lunar quadratures, was deemed unreliable.

ON THE STRENGTH OF BRIDGES AND ROOFS.—By S. H. SHREVE, C. E. Second Edition (Revised). New York: D. Van Nostrand. Price $5.00.

This excellent work has justified the estimate of its value when it first appeared. A second edition revised by the author is now published.

No other work covers so much ground with so short a range of mathematical work. The student who is familiar with algebraic equations of the second degree, can understandingly read the treatise throughout. If he be furthermore familiar with the "Doctrine of Moments" and the principle of the "Triangle of Forces" he may soon familiarize himself with the analysis of all kinds of framed structures.

A MAP OF THE RAILWAY SYSTEMS OF THE EASTERN PROVINCES OF CANADA. Prepared by the Hon. The Minister of Public Works.

We are indebted to the kindness of Mr. William Kingsford, Engineer in charge of the Canadian Railways, for an early copy of the above map.

It is an elegant sample of execution, and on a liberal scale of dimensions. The representation of different railway lines by different colors is a neat device and much facilitates ready reference.

PIONEER ENGINEER. By EDWARD DOBSON, C. E. London: For sale by D. Van Nos- Price $5.25.

This work is designed for engineers of some experience, and relates to operations connected with the settlements of waste lands in new countries. It embraces all kinds of work that are likely to engage the attention of engineers in any climate. It is, notwithstanding the design of the author, exceedingly rudimentary and very brief.

The illustrations are excellent and numerous

A BOOK ON BUILDING, CIVIL AND ECCLESIASTICAL. By Sir Edmund Beckett, Bart. London. For sale by D. Van Nostrand. Price, $3.75.

This is a popular treatise on such styles of architecture as are practiced at the present time. The work is written in a peculiar, lively strain which is the author's own, and which holds the reader's attention. The writer is never dull although in some places a little obscure. He treats the old authorities in Architecture with but little respect, and it must be acknowledged affords his readers just as little.

There is a healthy disdain of shams manifested throughout, and a thorough knowledge of the practical phase of building of all styles and ages. The illustrations are few and of medium quality.

GLASGOW SCIENCE LECTURES. London & Glasgow. William Collins, Sons & Co. For sale by D. Van Nostrand.

The series contains lectures before unscientific audiences by prominent scientists.

The Dawn of Animal Life: By Prof. W. C. Williamson, F. R. S.

Chemical Elements: Prof. S. H. E. Roscoe, F. R. S.

Is Man an Automaton? W. B. Carpenter, LL. D., F. R. S.

Coal and Coal Plants: Prof. W. C. Williamson, F. R. S.

Recent Researches into the Chemical Constitution of the Sun: By J. Norman Lockyer, F. R. S.

Kent's Cavern: Wm. Pengelly, F. R. S.

Navigation: Sir Wm. Thompson, LL. D.

WATER SUPPLY ENGINEERING. By Col. J. T. FANNING, M. A. S. C. E.

D. Van Nostrand has in preparation a work on Water Supply Engineering, adapted entirely to American practice. It will form a comprehensive Treatise on the Theory and Practice of Gathering and Storing Water for Power and Domestic Use, Clarification of Water, Flow of Water in Pipes and Canals, Raising of Water by Power, and on the Practical Construction of Reservoirs, Weirs, Dams, and Pipe Systems for the Distribution of Water in Cities and Towns. It will make a volume of about 400 pages, octavo, fully and amply illustrated with designs and diagrams.

MISCELLANEOUS.

FATHER SECCHI has written a letter to the French Academy of Sciences on the "Hydraulics of the Ancients." The monuments he mentions have been mostly discovered by him in the environs of Rome. The first mentioned by him is an aqueduct built at Alatri, 200 years before the Christian era. It is an inverted syphon, its lowest point being 101 meters below the orifice from which the water flowed into the town; so that it sustains at its bottom a weight of at least eleven atmospheres. The pipes of this aqueduct are of earthenware, buried in a thick bed of concrete; they were very firmly joined together along a length of 7½ miles. This work seems to have been the model on which Vitruvius founded his description of syphon aqueducts. The second remarkable relic of antiquity found at the same place is a complete system of drainage composed of enormous porous stone-ware pipes, a meter in length, fourteen centimeters in diameter, and only two in thickness. This was done to dry up a plain intended for military manœuvres. Next come inclined planes expressly laid down on substantial foundations and near the top of a mountain, in order to collect rain water on a large surface, with a basin to purify it, and cisterns to preserve it. This was done to provide the town of Segni with potable water. Then follow contrivances of the ancients for turning the water filtering through porous ground into the acqueducts by turning the clayey strata to account. They used also to rid water of its carbonates of lime by boiling, then cooling it again by applying snow to the outside. They likewise had an ingenious way of cooling their "aqua tepular," which was too warm for drinking after it had been brought over to the Capitol. Father Secchi

has discovered the spring whence it came, and found that it marks 18 deg. Cent.—64 Fah.—in winter. The Romans used to mix it with water from the Julia, which only marked eleven deg. The other spring, now called "Preziosa," issues from an old volcanic crater.

AIR IN MINES.—At the last meeting of the North Staffordshire Mining Institute a paper by Mr. Wardle, of Burslem, was read on this subject.

In the course of it, Mr. Wardle said the temperature of the earth increased as they descended at about 1° Fah. for every 50 feet to 60 feet. At the deep coalpit at Dukinfield the temperature was constantly 75° Fah. at a depth of 2,151 feet, and at a depth of 17 feet it was only 1° Fah., which gave an increase of 1° Fah. for every 89 feet only. The average degree of temperature of the earth was 1° Fah for every 55 feet in descent to a depth of 1,800 feet, and afterwards 1° Fah. for every 44 feet. At 10,060 feet the temperature would be 212° Fah. provided all other circumstances remained the same; at twenty miles, 1,760° Fah.; and at fifty miles it would be 4,600° Fah., heat sufficient to melt any known metal. Thus, the deeper the shafts of their coal mines the greater the amount of natural ventilation they would obtain. A current of air, travelling at a speed of 10 feet per second, gave a pressure of .492 lb. to the square foot; at 16 feet, = .989; at 51.34,=6.027; and at 200,=39.2, as experienced on the surface of the earth. These might be described as—first, a breeze; second, a light gale; third, a gale; and, fourth, a hurricane. Increased velocity of wind meant greater friction or higher water-gauge. Air was perfectly elastic; by pressure it could be squeezed into less bulk, and if that pressure were withdrawn, it filled the same space as formerly. Heat had the same effect upon it as pressure. A cubic foot of air weighed 523 grains; a cubic foot of water weighed 1,000 oz.; a cubic foot of watery vapor weighed only 272 grains. So that the more vapor there was in the air the lighter it would be. Friction was estimated by the force required to overcome it. Friction of air increased or decreased in the same proportion that the extent of the rubbing surface exposed to the air increased or decreased. A circular airway offered less resistance in proportion to its area than any other form, because its circumference was less in proportion to its area than the perimeter of any other figure. Airways should be as large and with as smooth a surface as possible. Splitting the air-current was preferable to taking the whole current of air round the workings in one body. Generally speaking, splitting the air increased the quantity of air obtained by a given expenditure of power, but the benefits to be derived from splitting were limited by the area of the shaft.

THE curious glass beads called *aggry*, which are valued in Ashantee like diamonds, and which are found deep in the ground in the Dinkira, Akim, Warsaw, Ashantee, and Fantee countries, are supposed to be of ancient Egyptian manufacture. If so, they prove that the Egyptians surpassed the moderns in some respects in making glass. "The variegated strata," says "Johnson's Encyclopædia," now nearly ready for publication, "of the aggry beads are so firmly united, and so imperceptibly blended, that the perfection seems superior to art. The surfaces of some are covered with flowers and regular patterns so very minute, and the shades so delicately softened one into the other and into the ground of the bead, that nothing but the finest touch of the pencil could equal them. The agatised parts disclosed flowers and patterns deep in the body of the bead, and thin shafts of opaque colors run from the center to the surface." The recent Ashantee war has made the public in England somewhat familiar with these beautiful beads. There is observed in them different colored clays baked together without blending, as well as certain peculiarities of manufacture which cannot be well explained. It is remarkable that these beads bear some resemblance to the celebrated *glain neidyr*, or Druid holy snake beads of glass found in Wales.

ELECTRIC ILLUMINATION.—Although the light now for some time in use in the Northern of France Railway station in Paris is economically obtained by means of the Gramme apparatus, there has been one point upon which improvement has been desired. A single light, as used in Paris, although placed at a great height, necessarily throws many very heavy shadows, which contrast most inconveniently with the blinding intensity of the light within its immediate neighborhood The discomfort attending the brightness of the light has been somewhat relieved by glass shades, but the shadows are, although less severe, still inconvenient. It has hitherto been found impossible sufficiently to multiply the number of lights so as to avoid these defects, but a discovery has recently been made by M. Jablockhoff which seems destined to bring the electric light into common use. M. Denayrouse has brought the discovery before the Academy of Science, and it seems that it offers, with little extra cost, an efficient means of procuring several lights from one source of electricity, and of regulating the positions of the carbon points. The most delicate part of the electric light apparatus has been this adjustment of the distance between the carbon points, and it is here that M. Jablockhoff steps in from quite a new path. Instead of placing the carbons end to end, he places them parallel with each other, and separated by some insulating material. The whole is then placed in a cylinder of refractory material in the form of a double carbon wicked candle. By this arrangement the two carbons burn by their lower extremity, there being no necessity for regulators, as the insulating material keeps them at a constant distance. This material as well as the cylinder is consumed in the same time as the carbons, its volatility augmenting the light. Previous to this discovery it was necessary to have a regulator for each lamp, and at great cost, but now a single source of electricity may feed a number of burners, thus permitting of the most effective distribution of the light.

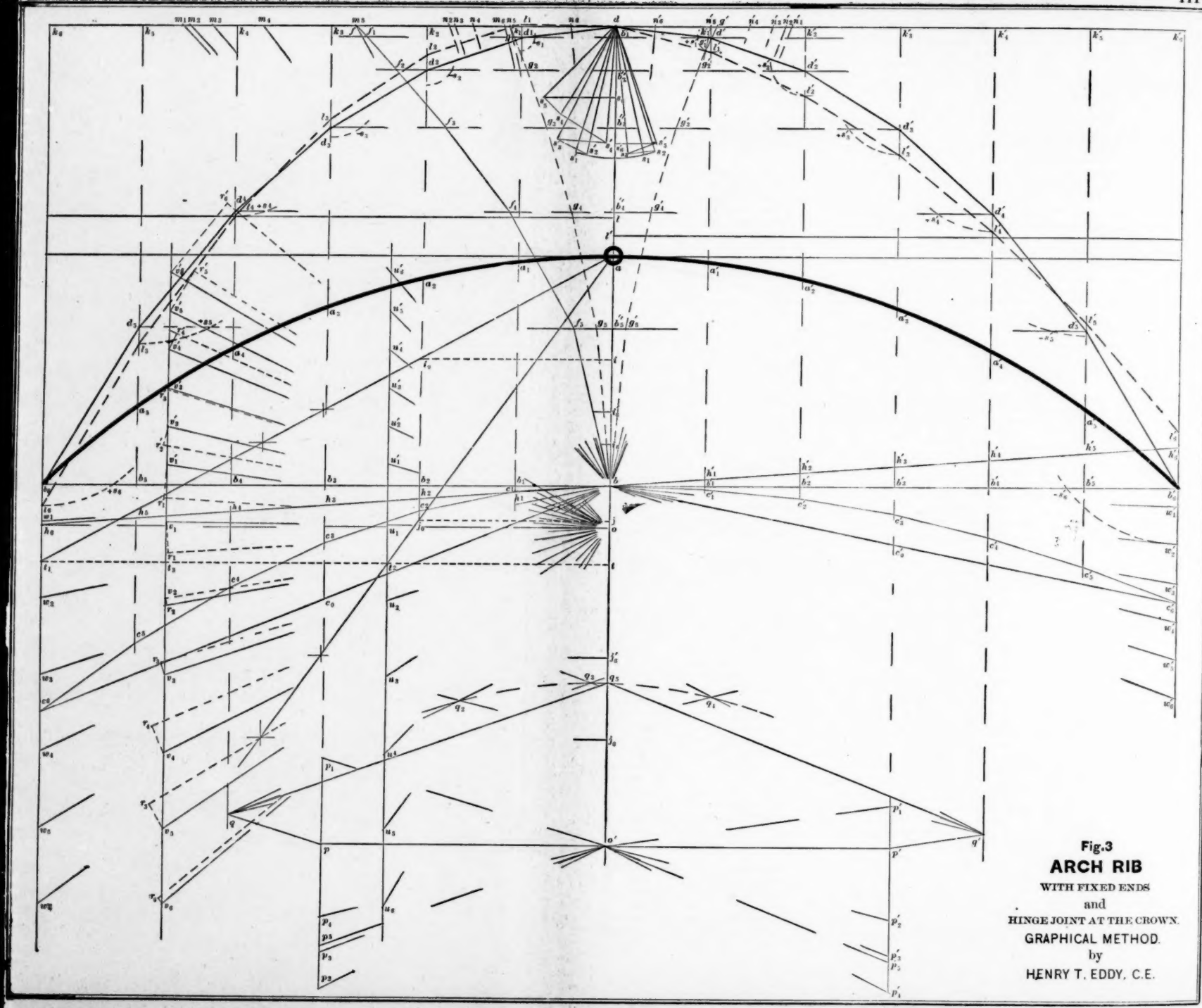


Fig.3

ARCH RIB

WITH FIXED ENDS

and

HINGE JOINT AT THE CROWN.

GRAPHICAL METHOD.

by

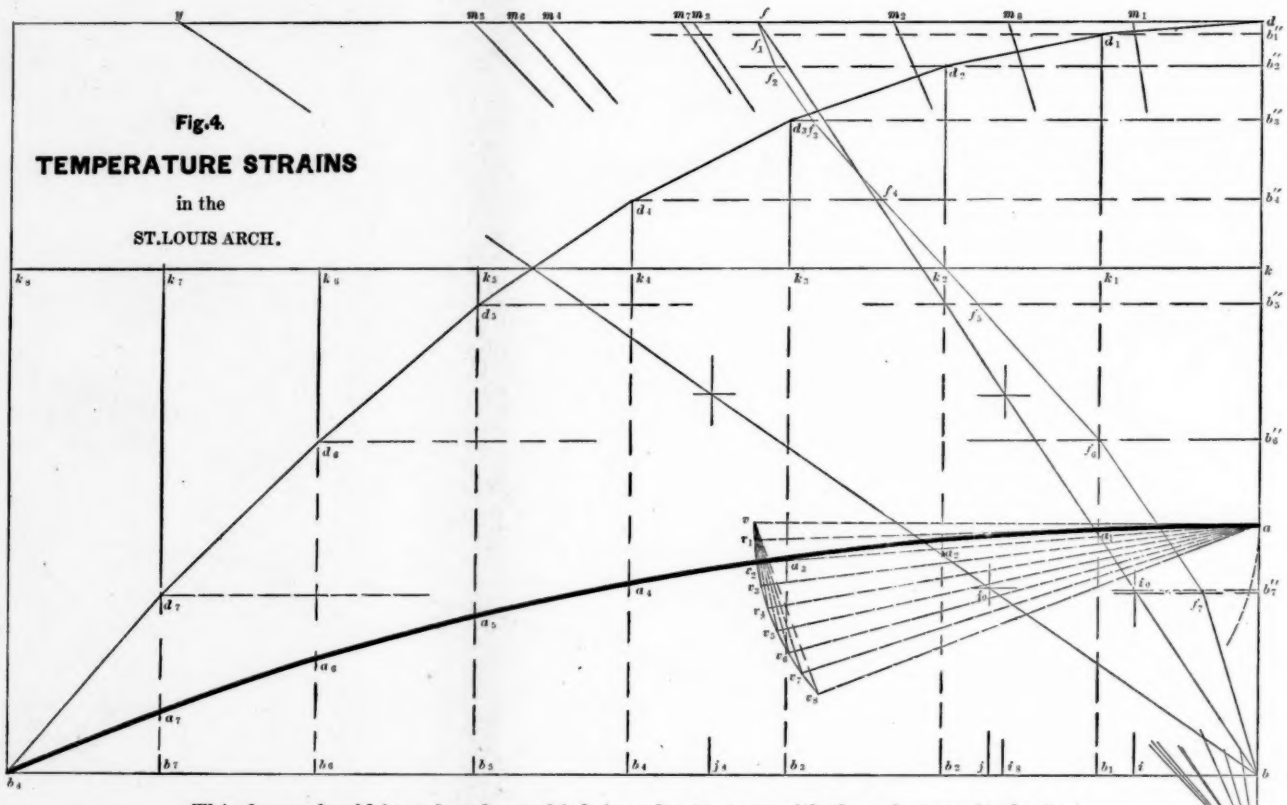
HENRY T. EDDY, C.E.

Fig.4.

TEMPERATURE STRAINS

in the

ST.LOUIS ARCH.



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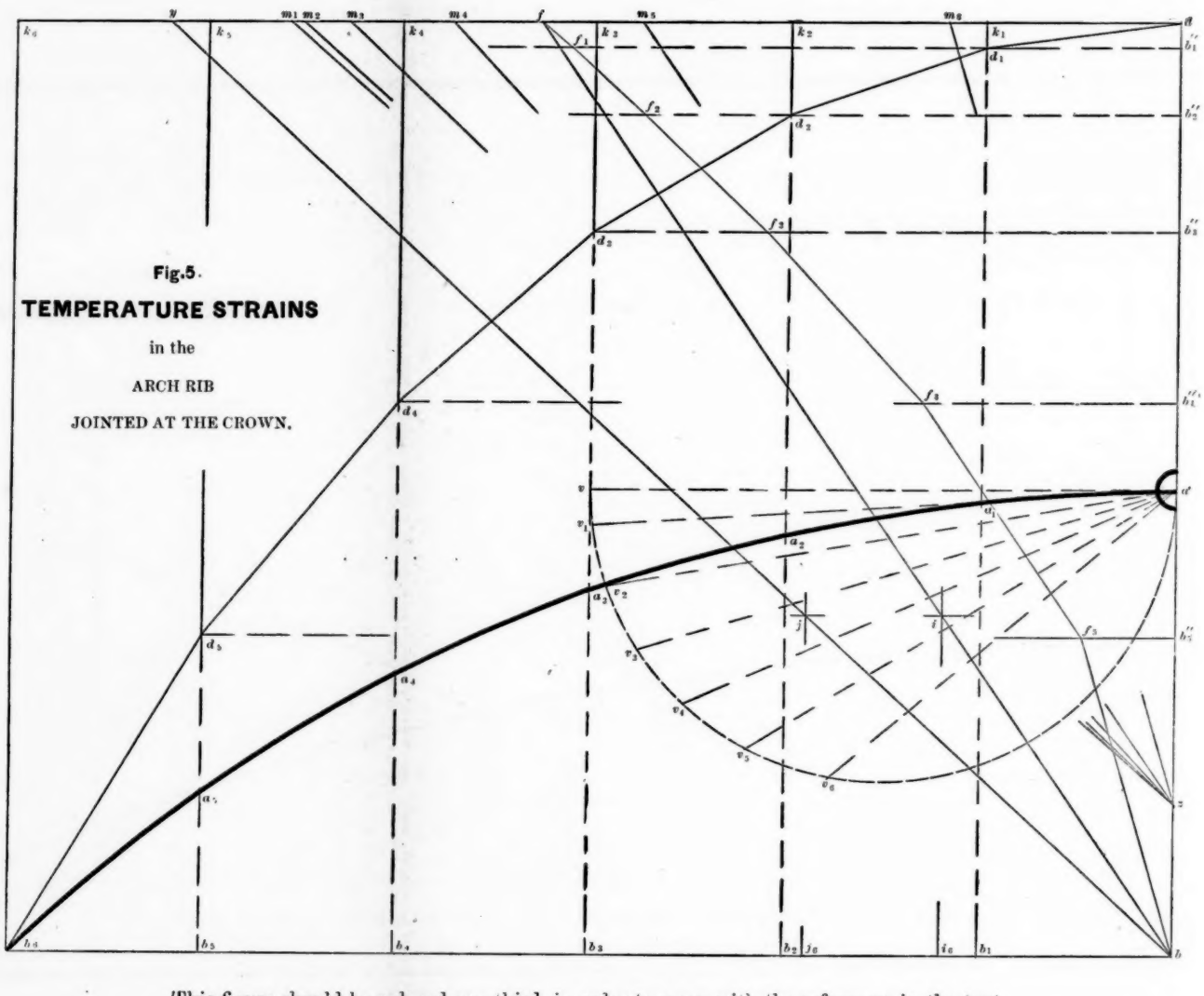

Fig.5.

TEMPERATURE STRAINS

in the

ARCH RIB

JOINTED AT THE CROWN.

This figure should be reduced one-third, in order to agree with the references in the text.